TECHNICAL REPORT NO. 3-783

AN ANALYTICAL MODEL FOR PREDICTING CROSS-COUNTRY VEHICLE PERFORMANCE

APPENDIX B: VEHICLE PERFORMANCE IN LATERAL AND LONGITUDINAL OBSTACLES (VEGETATION)

VOLUME II: LONGITUDINAL OBSTACLES

by

C. A. Blackmon

D. D. Randolph

July 1968

Sponsored by

Advanced Research Projects Agency

and

Development Directorate

U. S. Army Materiel Command

Service Agency

U. S. Army Materiel Command

Conducted by

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of U. S. Army Engineer Waterways Experiment Station.

54

DISCLAIMER NOTICE

TECHNICAL REPORT NO. 3-783

AN ANALYTICAL MODEL FOR PREDICTING CROSS-COUNTRY VEHICLE PERFORMANCE

APPENDIX B: VEHICLE PERFORMANCE IN LATERAL AND LONGITUDINAL OBSTACLES (VEGETATION)

VOLUME II: LONGITUDINAL OBSTACLES

by

C. A. Blackmon

D. D. Randolph

July 1968

Sponsored by

Advanced Research Projects Agency

and

Development Directorate

U. S. Army Materiel Command

Service Agency

U. S. Army Materiel Command

Project No. 1-V-0-25001-A-131

Conducted by

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

FOREWORD

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Secretary of Defense (OSD), Advanced Research Projects Agency (ARPA), and is a portion of one task of the overall Mobility Environmental Research Study (MERS) sponsored by OSD/ARPA for which the WES was the prime contractor and the U. S. Army Materiel Command (AMC) was the service agent. The broad mission of Project MERS was to determine the effects of the various features of the physical environment on the performance of cross-country ground contact vehicles and to provide therefrom data that can be used to improve both the design and employment of such vehicles. A condition of the project was that the data be interpretable in terms of vehicle requirements for Southeast Asia. The funds employed for this study were allocated to WES through AMC under ARPA Order No. 400. Some funds for preparation and publication of this report were provided by the Development Directorate, AMC, under Department of the Army Project 1-V-0-25001-A-131, Military Evaluation of Geographic Areas. The study was performed during the period June 1964 to November 1965 under the general guidance and supervision of the MERS Branch of the WES, the staff element of WES responsible for the technical management and direction of the MERS program.

This appendix is one of seven to the report entitled An Analytical Model for Predicting Cross-Country Vehicle Performance. These appendixes are:

A. Instrumentation of Test Vehicles

B. Vehicle Performance in Lateral and Longitudinal Obstacles (Vegetation)

   Volume I: Lateral Obstacles

Volume II: Longitudinal Obstacles

C. Vehicle Performance in Vertical Obstacles (Surface Geometry)

D. Performance of Amphibious Vehicles in the Water-Land Interface (Hydrologic Geometry)

E. Quantification of the Screening Effects of Vegetation on Driver's Vision and Vehicle Speed

F. Soil-Vehicle Relations on Soft Clay Soils (Surface Composition)

G. Application of Analytical Model to United States and Thailand Terrains

The study was conducted by personnel of the Area Evaluation Branch, Mobility and Environmental (M&E) Division, under the general supervision of Mr. W. J. Turnbull, Technical Assistant for Soils and Environmental Engineering; Mr. W. G. Shockley, Chief of the M&E Division; Mr. S. J. Knight, Assistant Chief, M&E Division; Mr. A. A. Rula, Chief, MERS Branch; Mr. Warren E. Grabau, Chief, Area Evaluation Branch; and Mr. Jack K. Stoll, Chief, Field Test Section, who was in direct charge of all phases of the study. Personnel of WES technical support elements provided major assistance in the field test program. Data reduction and preparation of plates and tables were accomplished by Messrs. W. T. Willis and V. J. Piazza under the direction of Mr. D. D. Randolph who performed the major portion of the data analysis. This report was written by Messrs. C. A. Blackmon and Randolph.

Directors of the WES during this study and preparation of this report were COL Alex G. Sutton, Jr., CE, and COL John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

	Page
FOREWORD	iii
NOTATION	vii
CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT	ix
SUMMARY	xi
PART I: INTRODUCTION	B1
Background	B1
Purpose and Scope	B1
PART II: TEST PROGRAM	B3
Location and Description of Test Areas	B3
Vehicles Used	B11
Vegetation Tested	B14
Types of Tests Conducted	B14
Test Procedures and Data Obtained	B15
Vegetation Data Obtained	B19
Soil Data Obtained	B20
PART III: ANALYSIS OF DATA	B22
Basis of Analysis	B22
Single Standing Tree Override Tests	B22
Bamboo Override Tests	B26
Multiple Tree Override Tests	B28
Notes, Observations, and Other Data Considered	B31
PART IV: CONCLUSIONS AND RECOMMENDATIONS	B35
Conclusions	B35
Recommendations	B35
TABLES B1-B4	
PLATES B1-B13	

BLANK PAGE

NOTATION

d_c Clump diameter, in.

d_s Stem diameter, in.

F_h Maximum horizontal pushbar force, lb

F_m Average horizontal pushbar force required to fail trees in multiple array, lb

F_s Computed average horizontal pushbar force required to fail an array of trees with no crown interference, lb

h_p Pushbar height, in.

K Constant for each pushbar height

S_m Unit fiber stress at the outside fiber of the section, psi

W_b Work required to fail a bamboo clump, lb-ft

W_m Work required to fail trees in multiple array, lb-ft

W_o Work required to override trees in multiple array, lb-ft

W_p Work required to fail a single standing tree, lb-ft

W_t Work required to override a single standing tree, lb-ft

BLANK PAGE

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles	1.609344	kilometers
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
inch-pound	0.011521	meter-kilograms
foot-pounds	0.138255	meter-kilograms
ton	907.185	kilograms

BLANK PAGE

SUMMARY

A total of 372 tests were conducted with one tracked and one wheeled vehicle at the NASA Marshall Space Flight Center, Miss., Eglin Air Force Base, Fla., Pran Buri, Thailand, and Khon Kaen, Thailand. The general purpose of these tests was to obtain data relating characteristics of longitudinal obstacles to vehicle performance in terms suitable for use in developing that portion of the analytical model for cross-country performance. The specific purposes were (a) to determine the maximum horizontal force and total work required to override single standing trees of a range of sizes at various speeds and pushbar heights and (b) to determine average horizontal force and total work required to override trees in multiple array. Empirical relations are presented to support the conclusions that pushbar force required to fail trees singly and in multiple array, work required to fail trees singly and in multiple array, and work required to override a single standing tree may be predicted from stem diameter(s). A method is suggested for predicting work required to override trees in multiple array. The results of the tree-felling tests in the Tunguska meteorite area were confirmed, with a single exception noted, and discussed. It is recommended that additional testing be done in areas of soft soil to determine the effect of soil strength on uprooting, and in grass and brush areas to determine the effect of small vegetation on speed.

AN ANALYTICAL MODEL FOR PREDICTING CROSS-COUNTRY VEHICLE PERFORMANCE

APPENDIX B: VEHICLE PERFORMANCE IN LATERAL AND LONGITUDINAL OBSTACLES (VEGETATION)

VOLUME II: LONGITUDINAL OBSTACLES

PART I: INTRODUCTION

Background

1. The main text of this report describes the development of an analytical model for predicting the cross-country performance of a vehicle. The model was based on an energy concept within the framework of classical mechanics that requires cause-and-effect relations be established between discrete terrain factors and vehicle response. This volume of Appendix B deals with the effects of a single terrain factor--longitudinal obstacles. The term "obstacle" in general refers to all features of the terrain, except soil, that are inhibitory to vehicle mobility. The obstacle-effects spectrum on vehicle mobility ranges from complete immobilization to minor speed reduction. For the purpose of the overall study, obstacles were categorized according to the direction of motion forced upon a vehicle negotiating the obstacle, i.e. vertical, lateral, or longitudinal.

2. Vegetation, such as small trees, shrubs, bushes, grasses, etc., that a vehicle can override causes neither vertical nor lateral motion to any marked degree but creates a resisting force parallel to the longitudinal axis of the vehicle that acts to slow the rate of forward motion, hence the nomen longitudinal obstacles.

3. Although very little information has been published on tree override, an empirical relation between felling moment of trees and stem diameter has been published along with some interesting conclusions from tree-felling tests in the Tunguska meteorite area in Russia.

Purpose and Scope

4. This appendix describes the longitudinal obstacle tests conducted

in the United States and in Thailand during the period August 1964-November 1965. The general purpose of these tests was to obtain data relating characteristics of longitudinal obstacles to vehicle performance in terms suitable for use in developing that portion of the analytical model for cross-country performance. The specific purposes were (a) to determine the maximum horizontal force and total work required to override single standing trees of a range of sizes at various speeds and pushbar heights and (b) to determine average horizontal force and total work required to override trees in multiple array.

5. Two types of tests were originally scheduled--single standing tree override and multiple tree override. When it became apparent that bamboo fit neither of these, a third type was added--bamboo clump override.

6. This investigation was limited to trees and bamboo in areas of firm soil.

PART II: TEST PROGRAM

Location and Description of Test Areas

NASA Marshall Space Flight Center

7. Single standing tree override tests and multiple tree override tests were conducted at the NASA Marshall Space Flight Center, Hancock County, Miss. (fig. B1). The locations of the test sites are shown in fig. B2. The test sites were level to gently sloping (less than 2 percent) and free of surface irregularities; grass and some small bushes were growing on the sites (fig. B3). Trees at the sites were coniferous, hardwood, or coniferous and hardwood mixed, with stem diameters ranging from 0.3 to 13.5 in.* Soils in the NASA area were classified as ML, CL-ML, CL, SC-SM, SM-SC, and SP-SM according to the Unified Soil Classification System (USCS). Average cone index in the 0- to 6-in. layer ranged from 80 to 533, and in the 6- to 12-in. layer from 112 to 750.

Eglin Air Force Base

8. Single standing tree override tests and multiple tree override tests were conducted at the Eglin Air Force Base test area, Fort Walton, Fla. (fig. B1). The locations of the test sites are shown in fig. B4. The test sites were level to gently sloping (less than 2 percent), were free of surface irregularities except for an occasional stump hole, and supported grass and abundant small understory plants. Trees at the sites were hardwood or hardwood and coniferous mixed (fig. B5). The stem diameters ranged from 1.0 to 13.0 in. The soils were classified as SM or SP-SM according to the USCS. Cone index in the 0- to 6-in. layer ranged from 41 to 132 and in the 6- to 12-in. layer from 60 to 199.

Pran Buri, Thailand

9. Bamboo clump override tests were conducted at the Pran Buri test area (fig. B6). All the bamboo clump override tests were conducted at one test site about 300 ft square (fig. B7). The test area was level and free of surface irregularities (fig. B8). The stem diameter of the bamboo

---

* A table of factors for converting British units of measurement to metric units is presented on page ix.

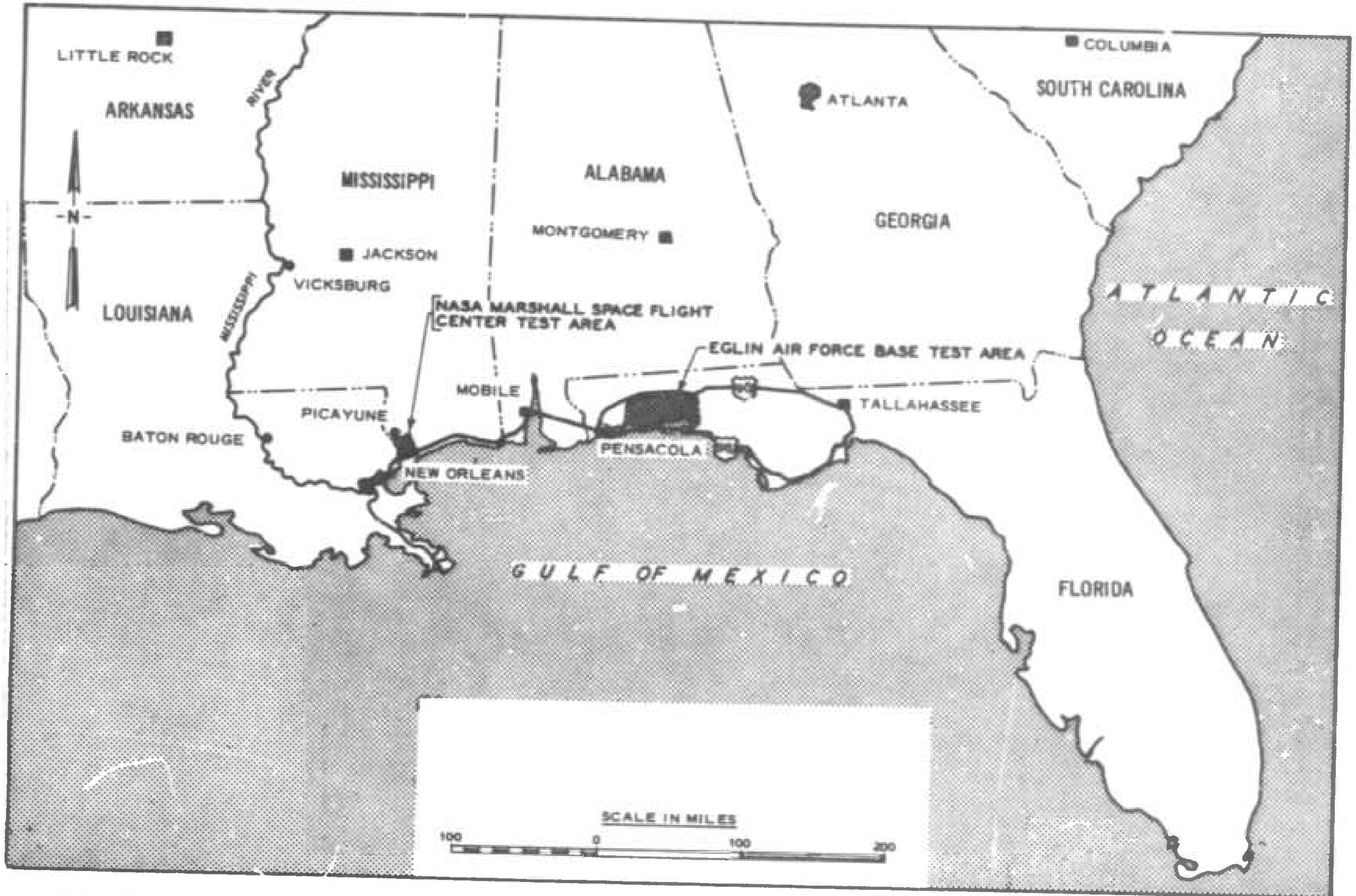


Fig. B1. Vicinity map, NASA Marshall Space Flight Center and Eglin Air Force Base test areas

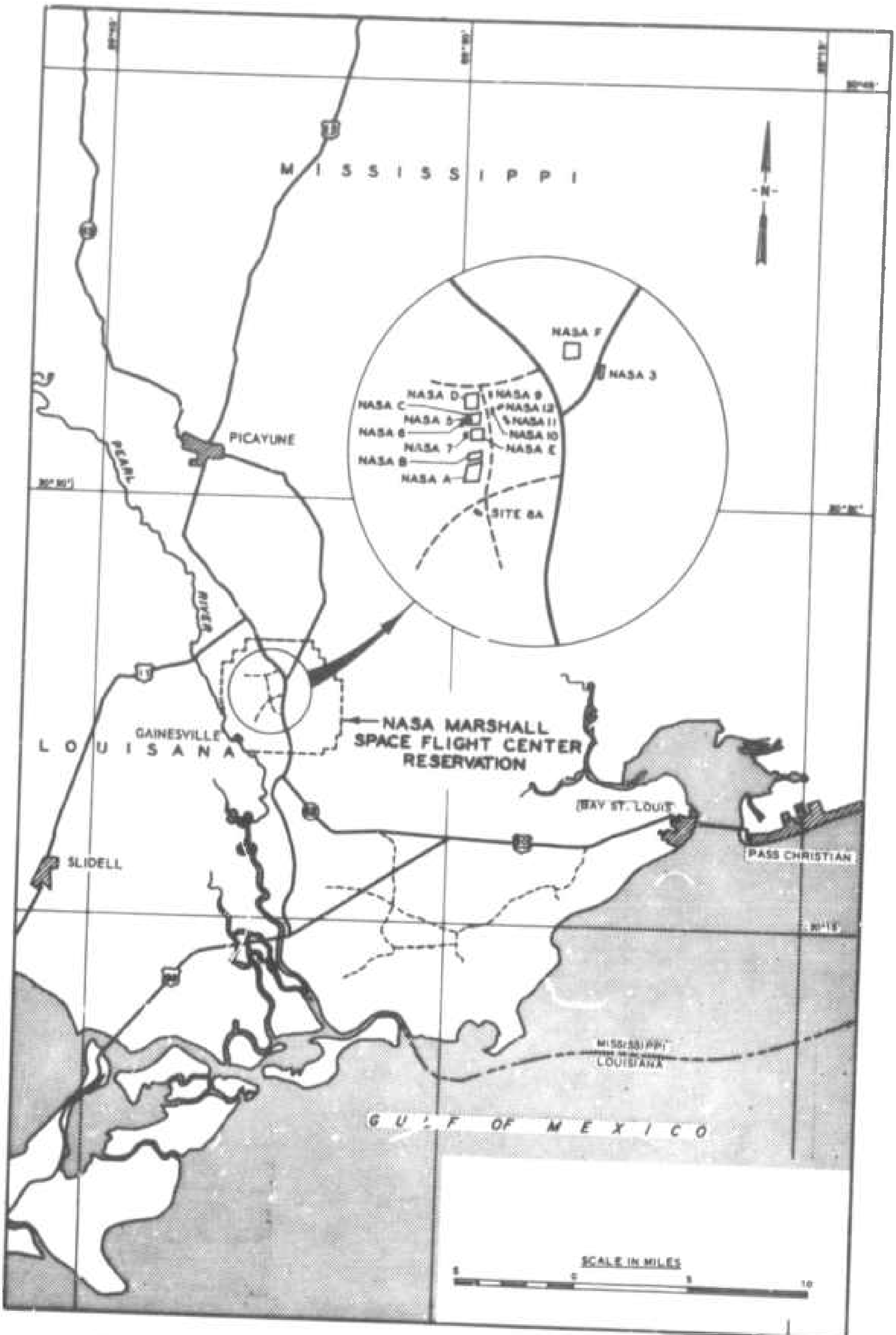


Fig. B2. Location of test sites, NASA Marshall Space Flight Center test area

Fig. B3. NASA Marshall Space Flight Center test area

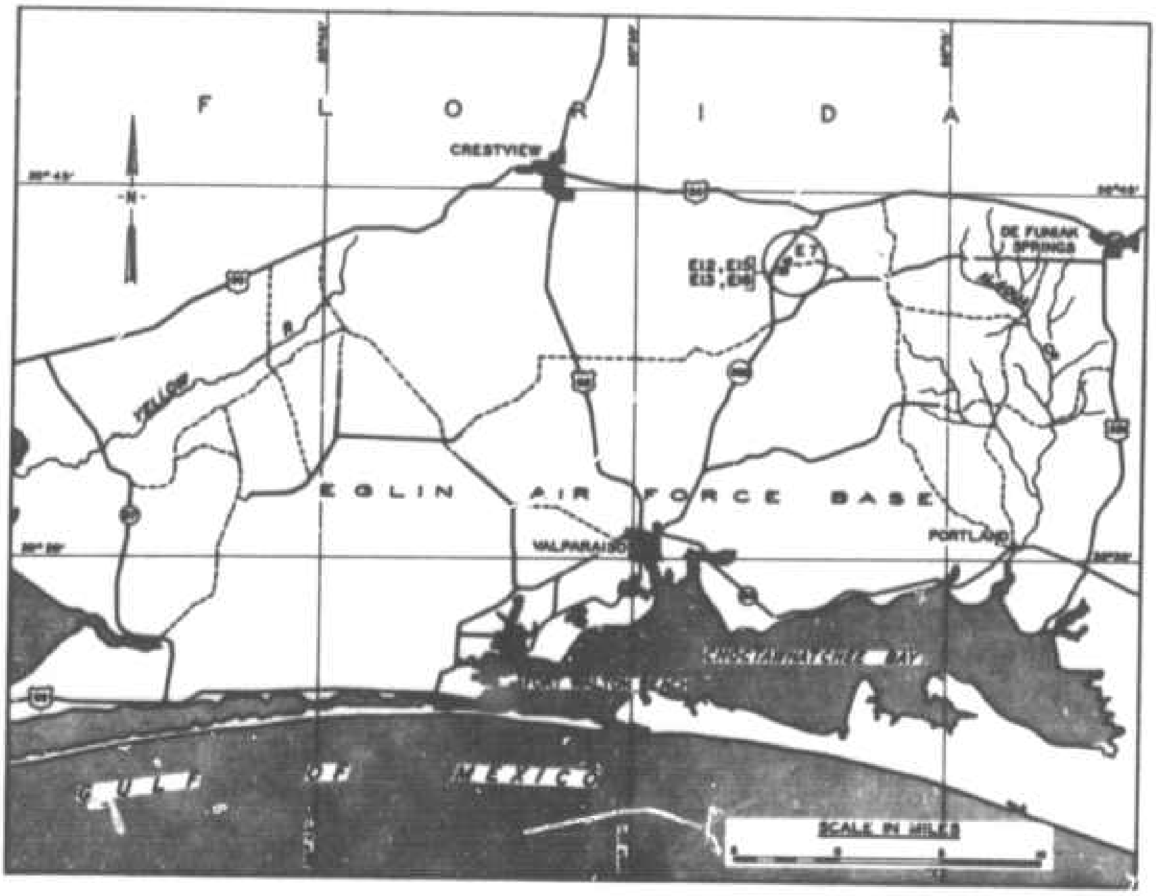


Fig. B4. Location of test sites, Eglin Air Force Base test area

Fig. B5. Eglin Air Force Base test area

ranged from 0.1 to 1.0 in., the clump diameter ranged from 3 to 40 in. at the ground surface, and the number of stems per clump ranged from 10 to 55. The soil was classified as SM in the 0- to 6-in. layer and ML in the 6- to 12-in. layer according to the USCS. The average cone index in the 0- to 6-in. layer ranged from 95 to 174 and in the 6- to 12-in. layer from 112 to 178.

Khon Kaen, Thailand

10. Single standing tree override tests were conducted in the Khon Kaen test area of Thailand (fig. B6). All the tests were conducted at one site about 400 ft square (fig. B7). The test site was level to gently sloping (less than 2 percent), was free of surface irregularities, and supported grass, small broadleaf understory plants, and Heing trees (fig. B9). The stem diameters ranged from 1.8 to 13.0 in. The soil was classified as SM in the 0- to 6-in. layer and as CL-ML in the 6- to 12-in. layer. The cone index ranged from 121 to 209 in the 0- to 6-in. layer and from 120 to 289 in the 6- to 12-in. layer.

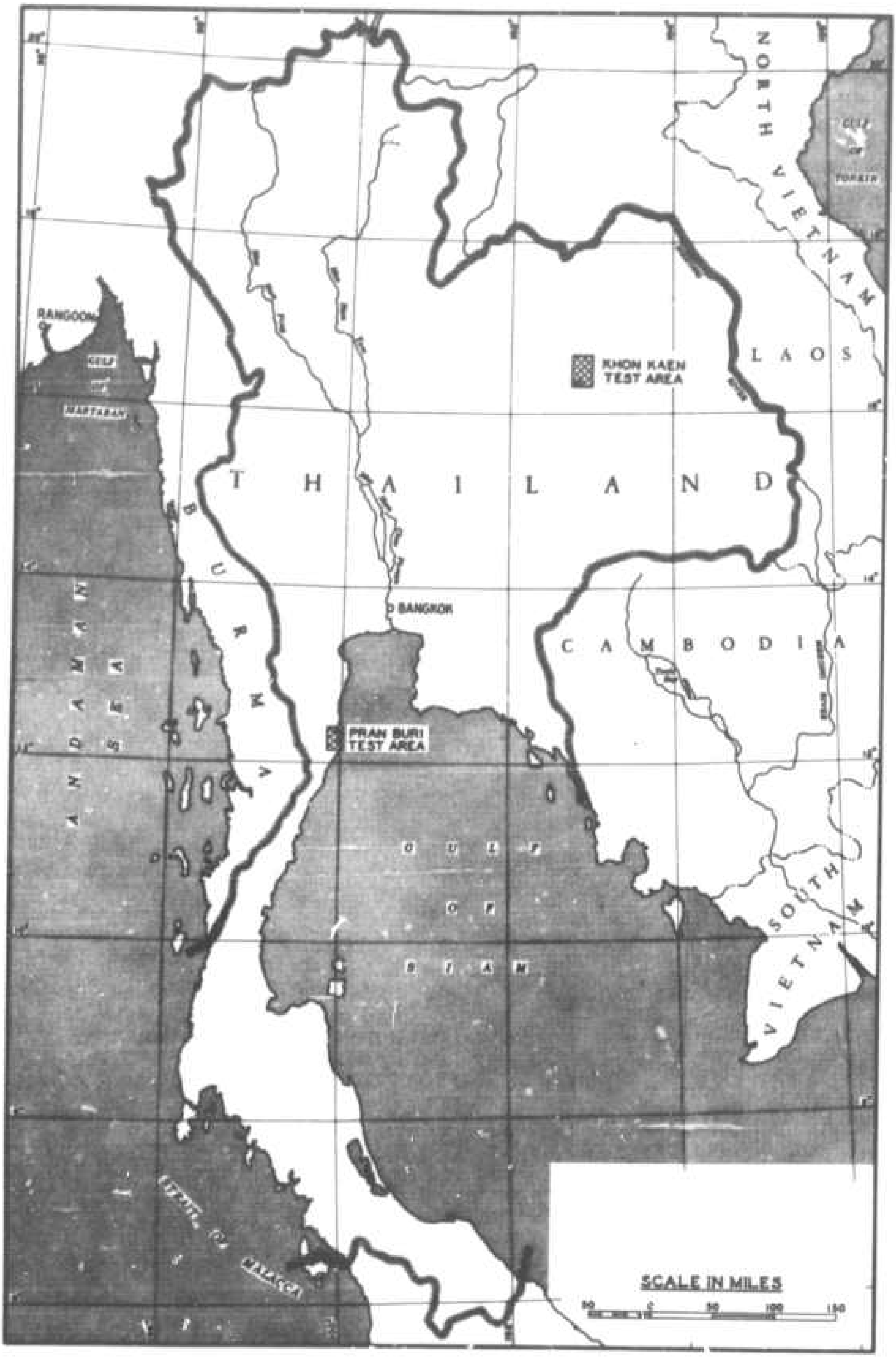


Fig. B6. Vicinity map, Khon Kaen and Pran Buri test areas

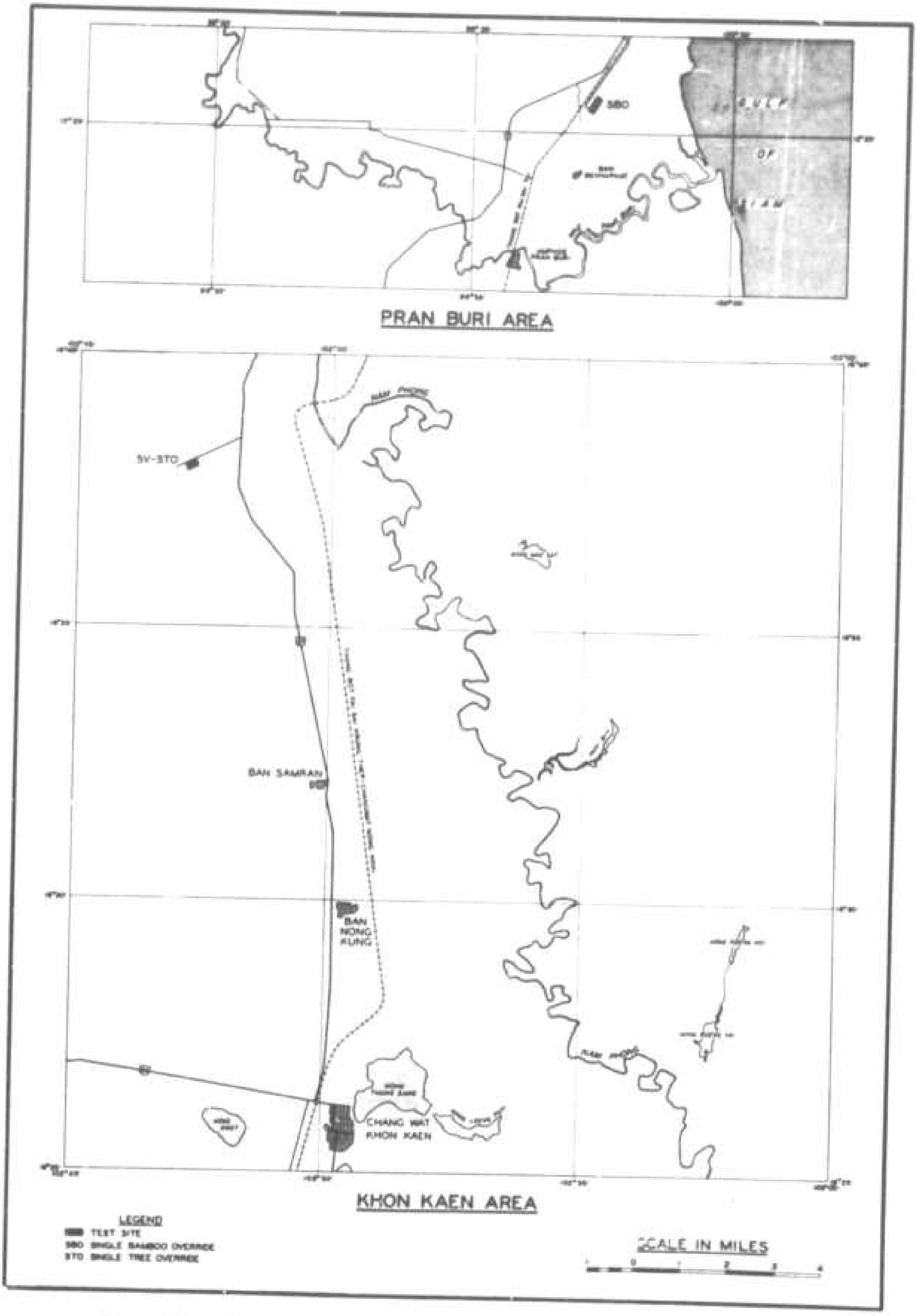


Fig. B7. Location of Pran Buri and Khon Kaen test sites

Fig. B8. Bamboo override test area, Pran Buri, Thailand

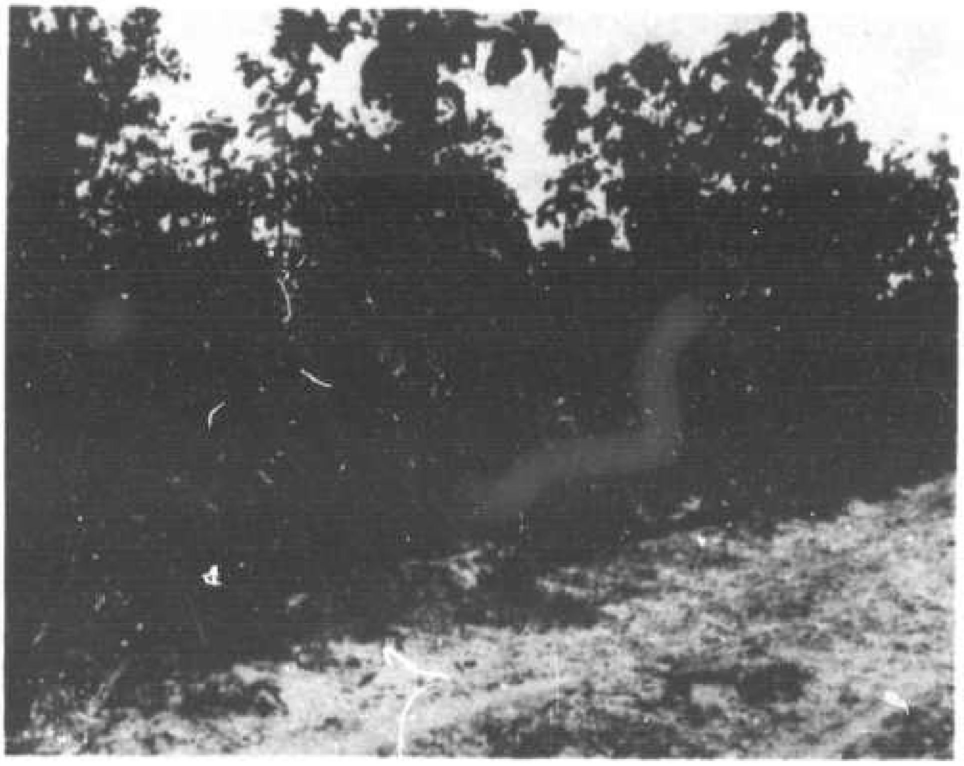


Fig. B9. Single standing tree override test area at Khon Kaen, Thailand

Vehicles Used

11. Two vehicles were used in these tests--an M37 3/4-ton cargo truck and an M113 armored personnel carrier. Pertinent physical characteristics of the vehicles are as follows:

M37 3/4-ton cargo truck	
Test weight, lb	7350-7645
Tires	
Size	9:00-16
Ply	8
Ground clearance, in.	10.8
Engine	
Type	Gasoline
Brake horsepower	78
Transmission	Manual, synchromesh
M113 armored personnel carrier (APC)	
Test weight, lb	19,515-23,896
Track	
Contact length, in.	105
Width, in.	15
Shoe, in.	6
Contact pressure, psi	7.5
Bogies on ground, per side	5
Ground clearance, in.	16.1
Engine	
Type	Gasoline
Brake horsepower	215
Transmission	Hydraulic, single stage multiphase

Photographs of the vehicles are included as figs. B10 and B11.

12. No comparison of the tree-failing capabilities (tree failure is defined in paragraph 32) of the two vehicles used in the investigation was contemplated as the vehicles were considered only as instruments for testing the vegetation. To this end, a heavy-duty pushbar was fabricated and mounted on each vehicle. The pushbar height of the M37 was fixed at 26 in. (fig. B12); the pushbar height of the M113 could be adjusted in 6-in.

Fig. B10. M37 3/4-ton truck

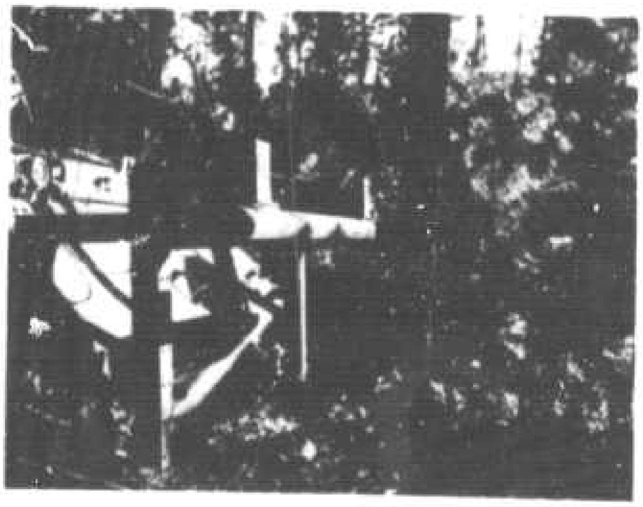
Fig. B11. M113 armored personnel carrier

increments between 20 and 56 in. (fig. B13). Both vehicles were equipped with fairly elaborate measuring and recording systems.*

* This instrumentation is discussed in detail in "An Analytical Model for Predicting Cross-Country Vehicle Performance; Appendix A: Instrumentation of Test Vehicles," by B. O. Benn and M. Keown, Technical Report No. 3-783, July 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Fig. B12. Pushbar mounted on M37 3/4-ton truck

a. Pushbar at 32 in.



b. Pushbar at 56 in.

Fig. B13. Pushbar mounted on M113 armored personnel carrier

Vegetation Tested

13. The vegetation tested consisted of coniferous and hardwood trees, and bamboo grass. Each tree overridden was identified by common name. The conifers included pine and cypress; the hardwoods included oak, hawthorn, and the Heing trees of Thailand. Bamboo grass was treated separately in this investigation.

Types of Tests Conducted

14. Although the tests were basically alike in that they sought the answer to the question "How much force and work are required to override a tree or group of trees, and to what measured physical characteristic of the tree can these be related?", there were some differences in the obstacles per se and the conduct of the tests. The types and number of tests in each of the four areas are listed below. It can be seen that the major effort was devoted to single standing tree override tests (333 tests in three areas).

Location	Single Standing Tree Override	Bamboo Clump Override	Multiple Tree Override	Total
NASA	196	0	12	208
Eglin	78	0	3	81
Pran Buri	0	24	0	24
Khon Kaen	59	0	0	59
Total	333	24	15	372

Single standing tree override tests

15. Single standing tree override tests were, as the name implies, conducted against one live standing tree with adjacent trees removed so that the vehicle could approach the tree in a straight line and the tree could fall without interference. These tests were conducted at speeds ranging from 0.0 to 17.1 mph and at five pushbar heights ranging from 20 to 56 in.

Bamboo clump override tests

16. Bamboo clump override tests were conducted against single clumps of bamboo carefully selected so that the vehicle could approach in a straight line and the bamboo clump could fall without interference. These tests were conducted with a single pushbar height (26 in.) and at speeds of approximately 2 mph with the exception of two tests at higher speeds.

Multiple tree override tests

17. Multiple tree override tests were conducted against an array of trees that permitted interference of the crowns as the trees were overridden. An approach strip was cleared so that the vehicle could attain the desired speed before entering the test site. These tests were conducted at approximately 2 mph and at a single pushbar height (26 in.).

Test Procedures and Data Obtained

Single standing tree override tests

18. Procedures. The vehicle accelerated to the desired contact speed at least 20 ft before striking the tree (fig. B14). The driver

Fig. B14. Pushbar striking tree in single standing tree override test

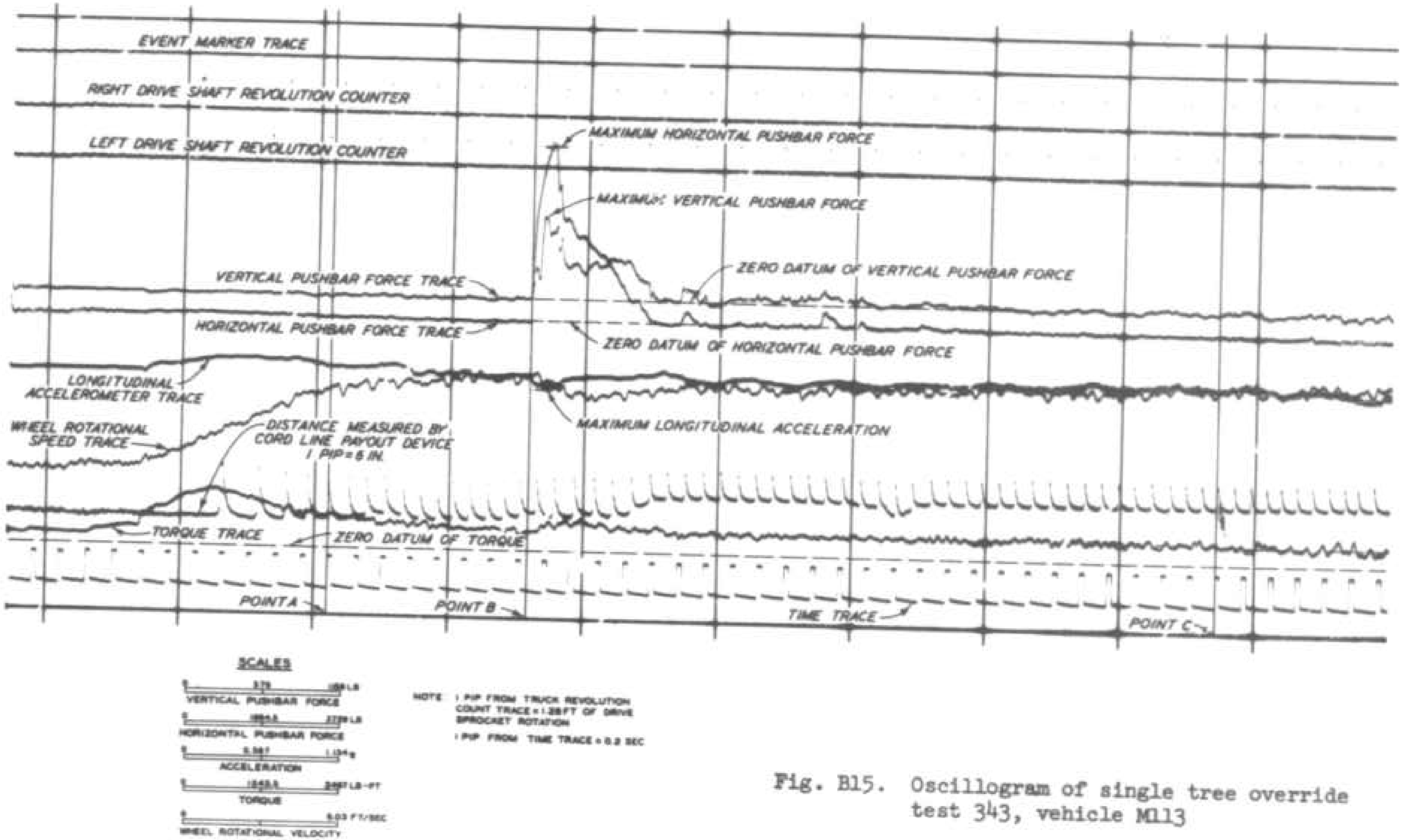


Fig. B15. Oscillogram of single tree override test 343, vehicle M113

attempted to maintain this speed until the vehicle had completely overridden the tree.

19. Data obtained. By means of electronic instrumentation installed on the test vehicle, continuous measurements of horizontal pushbar force, distance actually traveled, and time were made and recorded. In addition, for some tests vertical pushbar force, drive line torque, drive shaft revolutions, and wheel or track rotational speed and longitudinal acceleration were measured and recorded. An example of an oscillogram record, for test 343, is shown in fig. B15. A summary of the data read directly from the oscillogram, i.e. maximum horizontal pushbar force, maximum vertical pushbar force, and maximum longitudinal acceleration, and the data computed from the oscillogram, i.e. contact speed, work required to fail the tree, work required to override tree, and maximum tractive force is given in table B1.

Bamboo clump override tests

20. Procedures. The vehicle approached the clump at the desired speed and the driver attempted to maintain this speed until the vehicle had overridden the clump (fig. B16).

21. Data obtained. Instrumentation for the bamboo clump override tests was limited to only that needed to determine maximum horizontal pushbar force, work required to fail the clump, vehicle speed, and maximum longitudinal acceleration. A summary of these data is given in table B2.

Multiple tree override tests

22. Procedures. The vehicle approached the test site at a speed of approximately 2 mph in its

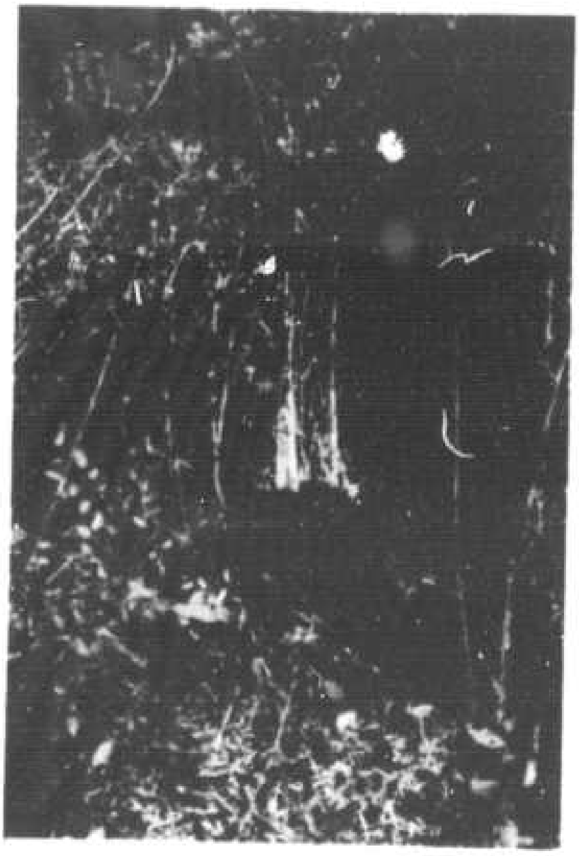


Fig. B16. Bamboo clump after being overridden

lowest gear and the driver attempted to maintain this speed while proceeding in as straight a line as possible through the test site overriding all trees in the path of the vehicle (fig. B17). Fig. B18 illustrates a multiple tree override test site after testing.

Fig. B17. Multiple tree override test. Note crown interference

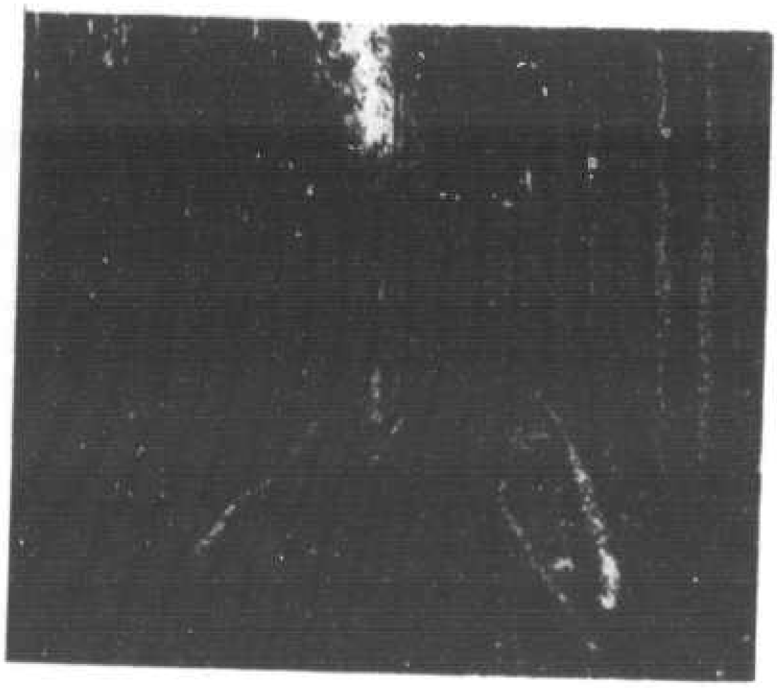


Fig. B18. Multiple tree override test site after testing

23. Data obtained. The instrumentation on the vehicle measured and recorded horizontal pushbar force, time, distance actually traveled, drive-shaft revolutions, longitudinal acceleration, and drive-line torque. A summary of the data read or computed from the oscillogram is given in table B3.

Vegetation Data Obtained

Single standing trees

24. For convenience in conducting the tests, ensuring that all necessary data were secured, and collating the test data, vegetation data, and soil data, each tree utilized in the single standing tree override tests was given a specific number. For each test the vegetation data consisted of the common name of tree, tree height, branching height, stem diameter at 42 in. aboveground, crown diameter, and mode of failure, and observations of unusual occurrences during the test. These data are given in table B1.

Bamboo clumps

25. Bamboo did not fall in the category of either conifers or hardwoods, and the tests were representative of neither single standing tree override nor multiple tree override. Various vegetation data were obtained during the course of the bamboo clump override investigation; however, only number of stems, stem diameter, and clump diameter are included in this report. These data are summarized in table B2.

Trees in multiple array

26. Vegetation data obtained for the multiple tree override tests included common names of trees, height, stem diameter, structural cell* diameter, and mean tree spacing. A planimetric map of each multiple tree

---

* The structural cell concept with its derivatives, mean tree spacing, nearest neighbor distance, etc., has been explored with some intensity by the U. S. Army Engineer Waterways Experiment Station. The concept is described in "Quantitative Physiognomic Analysis of the Vegetation of the Florida Everglades," by H. L. Mills, Contract Report No. 3-72, 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.; prepared by Marshall University, Huntington, W. Va.

override test site was prepared; an example is shown in fig. B19. Immediately after each test the number of trees actually overridden was determined. These data are summarized in table B3.

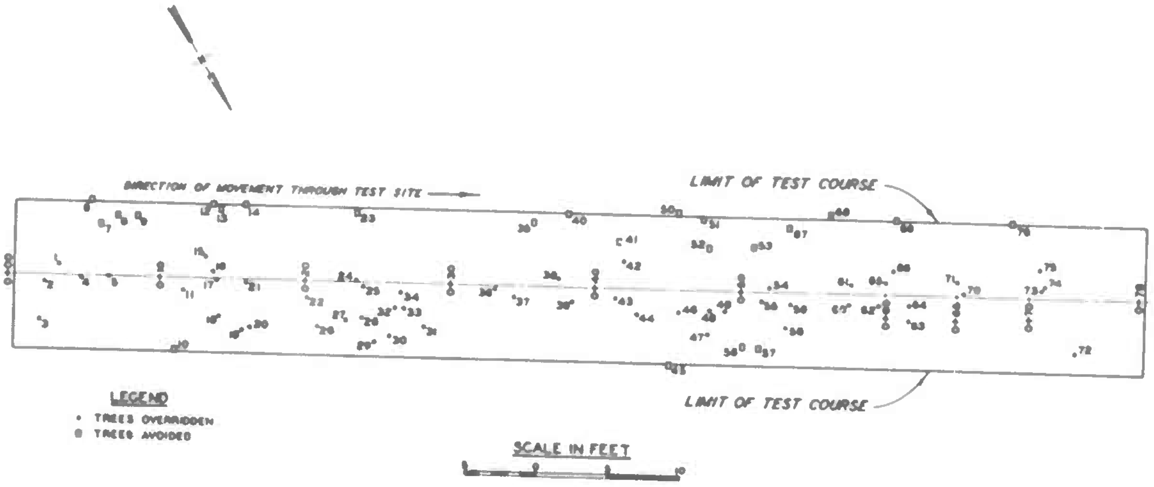


Fig. B19. Planimetric map of multiple tree override, test site NASA 6

Soil Data Obtained

27. During this study the primary reasons for obtaining soil data were to describe the test areas adequately and to ensure that there was no radical change in soil strength or composition at a test site. The effect of soil characteristics on the force required to bend or shear a tree stem appeared nil to the experimenters (possibly because the soils in the test area were firm), and while an effect of soil characteristics on the force required to uproot a tree might be hypothesized, any investigation of such effect was beyond the scope of this study. However, since soil strength and composition are necessary to describe a test area, and for possible, if indeed not probable, future use, the soil data discussed in the following paragraphs are included in this report.

Cone index

28. Cone indexes were measured at the surface and at 3-in. vertical increments to a depth of 30 in. around the base of each tree used in the single standing tree override tests, to a depth of 24 in. around the base

of each bamboo clump, and to a depth of 18 in. along the path of the vehicle in the multiple tree override tests. The average cone indexes for each 6-in. layer are shown in tables B1, B2, and B3, respectively.

Moisture content

29. Average moisture content was determined for the 0- to 6-in., 6- to 12-in., and 12- to 18-in. soil layers for the area around the base of each tree used in the single standing tree override tests. A summary of these data is included in table B1. Moisture content was determined somewhat less frequently for the multiple tree override tests (table B3) and not at all for the bamboo clump override tests.

Soil samples

30. Samples for classification of the soil according to the USCS were obtained from the 0- to 6-in., 6- to 12-in., and 12- to 18-in. soil layers around the base of each tree used in the single standing tree override tests, and from the 0- to 6-in. and 6- to 12-in. soil layers along the path of the vehicle in the multiple tree override tests. A summary of these data is shown in tables B1 and B3, respectively. Because prior reconnaissance had shown the near uniformity of the soil in the area where the bamboo clump override tests were conducted, additional samples for laboratory analysis were not taken at the time of testing. As a matter of record, the USCS soil type in the area of the bamboo clumps is shown below.

Layer	USCS Type	Name
0- to 6-in.	SM	Silty sand
6- to 12-in.	ML	Sandy silt

PART III: ANALYSIS OF DATA

31. The data collected in this test program are analyzed under four headings: Single Standing Tree Override Tests, Bamboo Clump Override Tests, Multiple Tree Override Tests, and Notes, Observations, and Other Data Considered. The conditions and assumptions upon which the analysis is based are described briefly in the following section.

Basis of Analysis

32. From a study of the results of the single standing tree override tests and a study of findings in other programs it was determined that the stem diameter was the tree characteristic that best correlated with the vehicle-tree interaction measurements; hence, stem diameter was selected as the independent variable to represent the tree in the analysis. It was considered that tree failure had occurred when uprooting of the tree, shear of stem, or deformation of the tree terminated the horizontal resistance to the pushbar. Other special considerations peculiar to a particular section of the analysis are discussed in the appropriate section.

Single Standing Tree Override Tests

Maximum horizontal pushbar force

33. Data from the tests of hardwoods and conifers at contact speeds of less than 4 mph and at pushbar heights of 20, 26, 32 and 38, and 56 in. are shown in plates B1, B2, B3, and B4, respectively. The dashed lines in these plates were derived by treating the tree as a cantilever beam. The fiber-stress equation states that the resisting moment at any cross section of a beam is equal to the unit stress (S_m) times the moment of inertia of the cross section with respect to the neutral axis divided by the distance from the neutral axis to the outermost fiber. In applying this equation to a tree, the resisting moment is the product of the horizontal pushbar force and pushbar height ($F_h \cdot h_p$), the moment of inertia of a cross section of a tree stem is $\pi d_s^4/64$, and the distance from the neutral axis to the

outermost fiber is $d_s/2$; the equation can be written as

$$F_h \cdot h_p = \frac{S_m \frac{\pi d_s^4}{64}}{\frac{d_s}{2}} \qquad \text{(B1)}$$

34. The ultimate unit stress for most of the trees overridden was approximately 7500 psi.* Substituting 7500 psi for the unit stress, the equation is reduced to

(For 20-in. pushbar height) $F_h = 36.8d_s^3$ (B2)

(For 26-in. pushbar height) $F_h = 28.3d_s^3$ (B3)

(For 38-in. pushbar height) $F_h = 19.4d_s^3$ (B4)

(For 56-in. pushbar height) $F_h = 13.1d_s^3$ (B5)

In plates B1-B4 note that although these are not lines of best fit, they do agree with the data points quite well. Two reasons are suggested for the variations:

a. The 7500-psi unit stress is only an approximate value.

b. The pushbar height is only an approximation of the length of the moment arm. In more than 50 percent of the tests, the failure occurred in the roots. (See discussion of number and types of failures, paragraph 51.)

35. The solid lines in plates B1-B4 represent the parallel lines of visual best fit. The equations of these curves are

(For 20-in. pushbar height) $F_h = 30.0d_s^3$ (B6)

(For 26-in. pushbar height) $F_h = 27.0d_s^3$ (B7)

---

* U. S. Department of Agriculture, "Wood Handbook," June 1940, Forest Products Laboratory, Washington, D. C.

(For 32- and 38-in. pushbar heights) $F_h = 22.0d_s^3$ (B8)

(For 56-in. pushbar height) $F_h = 15.0d_s^3$ (B9)

It can be seen in plates B1-B4 that these curves fit the data points slightly better, but it is also apparent that the difference in the two approaches is small.

36. Thus, within the range of conditions tested, on both a rational and an empirical basis, it is apparent that the maximum horizontal pushbar force required to fail a tree can be expressed as a function of stem diameter by the following general equation

$$F_h = Kd_s^3 \qquad \text{(B10)}$$

where K is a constant for each pushbar height.

37. Data from the tests of single standing trees at vehicle speeds of 4 to 17 mph and pushbar heights of 20 and 38 in. are shown in plate B5. Again, the empirical lines of best fit are shown as solid lines, and the theoretical (slow speed) values for the two pushbar heights are shown by the dashed lines. All but one of the data points fall above the respective theoretical curves, indicating that dynamic factors influence the maximum horizontal pushbar force-speed relation. It is conceivable that additional tests might lead to a "dynamic correction factor" as a function of speed; however, careful examination of the data collected in this program revealed that while there were readily apparent differences between the forces recorded during the tests at less than 4 mph and those recorded at 4 to 17 mph, the tests within each group disclosed no discernible pattern. On this basis it appears that predictions of the maximum horizontal force required to fail a tree at speeds of 4 to 17 mph should be made using the empirical curves.

Work required to fail
a single standing tree

38. The work required to fail a single standing tree (W_p) was computed from the horizontal pushbar force and distance measurements recorded

on the oscillogram and was plotted against the stem diameter of the tree overridden. The results of the tests of coniferous trees in the United States, hardwood trees in the United States, and hardwood trees in Thailand are shown in plates B6, B7, and B8, respectively. Note that a single curve appears to fit the data points on all three of these plots reasonably well. It can be seen that for the range of tree sizes and varieties tested, the work required to fail a single standing tree can be considered independent of tree type or geographical location and can be expressed as a function of stem diameter by the equation

$$W_p = 56.0d_s^3 \tag{B11}$$

Work required to over-
ride a single standing tree

39. While the mathematical computations for the total work performed by the pushbar are precise and the relation established is clear, it must be borne in mind that the work performed by the pushbar is only a part of the total work performed by the vehicle. The pushbar, for instance, is unaffected by the frictional drag of vegetation on the undercarriage of the vehicle, and the vehicle obviously does at least a modicum of work in propelling itself, even in the absence of vegetation. To this end, the parameter, "work required to override a single standing tree (W_t)," was defined as the total work done by the vehicle less that amount of work occasioned by motion resistance due to factors other than the tree itself, i.e. slope, soil, grass, etc. The value of this parameter was computed from the torque and distance traces on the oscillogram. The average torque at a constant speed in the approach lane was considered to be necessary to propel the vehicle and was subtracted from the torque recorded while the vehicle was overriding the tree. A plot of work required to override a single standing tree versus stem diameter is shown in plate B9. There is somewhat more scatter on this plot than is desired, but noting that tests from the United States and Thailand, of hardwood and conifers, at speeds less than 4 mph and from 4 to 12 mph are all incorporated, the scatter does not appear excessive. The curve drawn through the data points is parallel to the curve relating work required to fail a single standing tree to stem

diameter, thus permitting the latter value to be converted into work required to override a single standing tree by applying a constant, as follows

$$W_t = 100.0d_s^3 \quad \text{(B12)}$$

$$W_t = 1.786W_p \quad \text{(B13)}$$

Distance required to fail a single standing tree

40. All attempts to relate vehicle travel distance required to fail a single standing tree with tree characteristics, force measurements, or pushbar heights were unsuccessful. A summary of the distances the vehicles traveled to fail trees with the pushbar at heights of 20, 26, and 32 in. is given in table B4. From the table it can be seen that with a 20-in.-high pushbar the distance required to fail a single standing tree ranged from 2.1 to 9.4 ft, and the average distance was 5.67 ft; with a 26-in.-high pushbar the distances ranged from 3.5 to 8.2 ft and the average distance was 5.71 ft; and with a 32-in.-high pushbar the distances ranged from 3.0 to 8.7 ft and the average distance was 5.93 ft. The small increase in average distance as the pushbar height was increased from 20 to 32 in. is judged to be insignificant. Since the height of the bumper or leading edge of nearly all military vehicles falls within the 20- to 32-in. range, the average distance required to fail a tree with a military vehicle is considered to be the average of all tests or about 5.8 ft.

Bamboo Override Tests

41. Although a bamboo clump might appear, superficially at least, to be either a special case of a single standing tree or a multiple array of small trees, the test results were not compatible with those of either category. Plots of maximum horizontal pushbar force and pushbar work versus stem diameter, number of stems, clump diameter, and various combinations were studied to determine which feature of the bamboo clump would

give the best correlations. It was found that the plots with clump diameter as the independent variable yielded the least scatter; this is not unreasonable when it is considered that in all tests the bamboo clumps failed by uprooting, as previously illustrated (fig. B16, page B17).

42. The M37 truck became immobilized in four of the 24 bamboo override tests. In each of these four tests, the bamboo clump was actually failed, but when the vehicle attempted to completely override the clump at a slow speed, the front wheels of the vehicle were lifted clear of the ground and there was insufficient traction for the rear wheels to furnish the necessary forward thrust. In other tests, considerable wheel slip occurred as the vehicle was overriding the tree, resulting in torque measurements that were not amenable to analysis, hence the analysis is limited to maximum horizontal pushbar force required to fail a bamboo clump and work required to fail a bamboo clump as functions of clump diameter. The relations obtained are discussed in the following paragraphs.

Maximum horizontal pushbar force

43. A plot of the maximum horizontal pushbar force (F_h) required to fail a bamboo clump versus clump diameter is given in plate B10. The data from the four tests in which immobilization occurred are shown by closed symbols and are believed to be valid points on this plot since the immobilizations occurred after the pushbar had failed the clump. The curve drawn represents the line of visual best fit without reference to the data point from test 246. Notably, this test was conducted at the lowest speed and the bamboo clump overridden had the fewest stems of any in the program. This seems to point out that factors other than clump diameter, i.e. number of stems, speed of impact, and stem diameter, may significantly affect the maximum horizontal pushbar force. However, for the tests conducted, the equation of the curve in plate B10

$$F_h = 2.1d_c^{2.15} \qquad \text{(B14)}$$

represents a reasonable approximation of the force required to fail a bamboo clump.

Work required to fail a bamboo clump

44. As previously stated, the attempts to secure torque measurements during the bamboo clump override tests were not remunerative; hence, the work required to override a bamboo clump could not be determined from the available data. Nevertheless, the intermediate value, work required to fail a bamboo clump (W_b), was studied and a plot of these values versus clump diameter is shown in plate B11. The data from the tests resulting in immobilizations are shown by closed symbols and are held to be valid points. The curve drawn is the line of best visual fit, again without reference to test 246. The scatter of the data is less than that on the plot of horizontal pushbar force versus clump diameter, suggesting that work required to fail the clump is less affected by speed than is horizontal pushbar force. The equation of the curve in plate B11

$$W_b = 3.41 d_c^{2.15} \qquad \text{(B15)}$$

provides an acceptable method of predicting the work required to fail a bamboo clump within the range of sizes tested.

Multiple Tree Override Tests

45. Obviously it takes more effort to override trees spaced closely together than when each tree can fall free of interference by its neighbors. The increase is due principally to the interference of crowns as shown in fig. B18, page B18. The study of this increase was the principal purpose of the multiple tree override tests.

Average horizontal pushbar force

46. A plot of average measured horizontal pushbar force required to fail trees in multiple array (F_m) versus the average horizontal pushbar force that would have been required to fail the same combination of trees severally (F_s) as computed from the relations established in the single standing tree override tests is shown in plate B12. A sample computation of average pushbar force required for test 12 is shown as follows.

Distance ft	Tree No.	Stem Diameter (d_s), in.	Work Required to Fail Tree (W_p), lb-ft
25	85	5.7	10,371
	86	3.5	2,401
	103	3.1	1,668
	104	5.9	11,501
	105	3.6	2,613
	108	6.1	12,711
	109	4.2	4,149
		Total	45,414

$$F_s = \frac{45,414}{25} = 1817 \text{ lb}$$

It can be seen in plate B12 that the average force requirement for trees in multiple array was significantly greater than that required to fail the trees severally, even when the latter was as low as 136 lb. It can also be seen that the increase in average force required becomes greater as the computed average force required to fail the trees separately increases. The scatter of data appears well within the limit of experimental error and the equation given in this plot

$$F_m = 0.66F_s^{1.127} \qquad \text{(B16)}$$

appears to adequately define the average horizontal force demand of trees in multiple array within the limits encountered in this test program.

Work required to fail
<u>trees in multiple array</u>

47. A plot of measured work required to fail trees in multiple array (W_m) versus the summation of the work required to fail the same combination of trees severally as computed from relations developed in single standing tree override tests is shown in plate B13. In this plot it can be seen that the total measured work required to fail trees in multiple array was significantly greater than the total work required to fail the same combination of trees severally, and that the increase in work required by trees in multiple array became greater as the computed work required increased.

Again, the scatter of data appears quite reasonable and the equation given in this plate

$$W_m = 0.6 \left[\sum_{1 \to n} (W_p) \right]^{1.088} \tag{B17}$$

satisfactorily expresses the relation between work required to fail trees in multiple array and the summation of the work required to fail the same combination of trees individually.

48. Since the work required to fail a single standing tree (W_p in the equation above) has been shown to be a function of the stem diameter, combining equation B11 and equation B17 gives

$$W_m = 0.6 \left[\sum_{1 \to n} (56 d_s^3) \right]^{1.088} \tag{B18}$$

thus expressing work required to fail trees in multiple array as an exponential function of the stem diameters.

Work required to override
trees in multiple array

49. The work required to override trees in multiple array is, of course, greater than the work required to fail trees in multiple array for the same reasons that applied to single standing trees. Regrettably, the available data do not permit an empirical evaluation of the work required to override trees in multiple array. Torque meters were not available until late in the test program. Therefore, torque measurements were obtained only for tests 455, 458, and 459. However, because of wheel slip during the test and errors made in calibrations, the torque measurements were not reliable. Nevertheless, it is possible to make some inferences from the relations established herein.

50. It has been shown that the work required to override a single standing tree expressed as a function of the stem diameter (equation B12) is linearly related to the work required to fail a single standing tree expressed as a function of the stem diameter (equation B11), and may be equally as well expressed as a constant times the work required to fail a single standing tree (equation B13). In the absence of data indicating

otherwise, it appears that the same constant might be used to relate work required to fail trees in multiple array to work required to override trees in multiple array (W_o); then

$$W_o = 1.786 W_m \tag{B19}$$

and substituting in equation B18 and reducing

$$W_o = 1.07 \left[\sum_{1 \to n} (56 d_s^3) \right]^{1.088} \tag{B20}$$

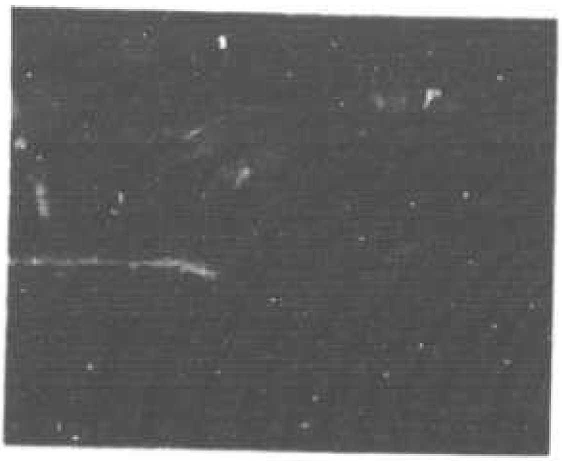
Notes, Observations, and Other Data Considered

Tree failure modes

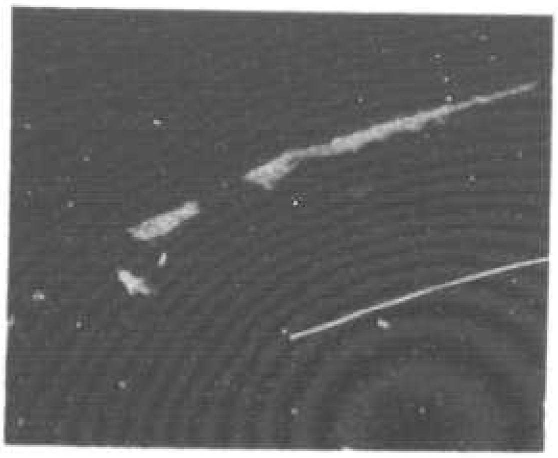
51. Illustrated in fig. B20 are the five tree failure modes exhibited in the override tests: type 1, in which the stem failed in compression; type 2, in which the stem failed in tension; type 3, in which the roots failed in tension and the soil in shear; type 4, in which the roots failed in tension without pronounced failure of the soil; and type 5, in which the stem deformed elastically. Types 1, 2, and 5 indicate that the root-soil system was stronger than the stem. Types 3 and 4 indicate that the stem was stronger than the root-soil system. The number of failures of each type is given in the following tabulation:

Type		No. of Failures
0	No failure indicated	11
1	Compression (stem)	10
2	Tension (stem)	37
3	Shear (soil) and tension (root)	215
4	Tension (root)	12
5	Elastic (stem)	41

There was no apparent indication that the type of failure, per se, significantly affected the test results.



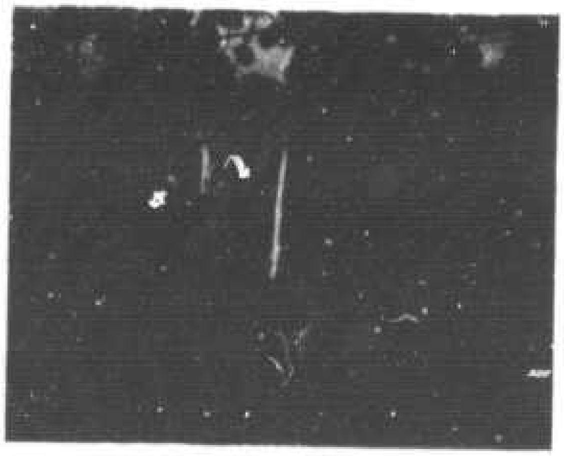
a. Type 1, compression (stem)



b. Type 2, tension (stem)

c. Type 3, tension (root) and shear (soil)

d. Type 4, tension (root)



e. Type 5, elastic (stem)

Fig. B20. Tree failure modes

Effect of soil conditions

52. Within the range of soil conditions encountered in this progr a, the effects of the soil type, soil strength, or moisture content could not be isolated. While it is believed that the method of analysis, i.e. push-bar force and torque minus motion resistance, satisfactorily eliminated or compensated for soil conditions insofar as the vehicle was concerned, there remains the fact that 215 single standing tree override tests, as shown in the preceding tabulation, resulted in soil shear and all of the bamboo clump override tests resulted in soil shear. It is axiomatic that soil shear strength varies inversely with moisture content, and it would be reasonable to expect the soil condition to have a significant effect on force required to fail or override a tree when the failure occurred in the soil. For instance, the tabulation in the following paragraph indicates a considerable difference in felling moments in dry and moist soils in the Tunguska Meteorite Area; however, as previously stated, the test areas used in the program reported herein were chosen to minimize the effect of soil strength on the vehicle, i.e. no significant rutting. It might be reasoned that when the soil is sufficiently strong, an increase in strength does not result in a significant increase in vehicle performance; then the increase in resistance to uprooting a tree would also be insignificant. This is, however, beyond the scope of this test program.

Data from other sources

53. In a report of the preliminary results from the 1961 combined Tunguska Meteorite Expedition, Florenskii* described a series of tests in which the felling moment of trees was determined by means of a winch and a dynamometer. Results of these tests yielded the following conclusions: (a) there is no relation between felling moment and species and age of a tree, (b) there is a distinct relation between moment and tree diameter, analytically nicely described by a parabola, (c) the parabolas are completely identical for fine and rocky soils, (d) the scatter of the data diminishes in inverse proportion to the diameter of the tree, (e) the felling moments of trees in dry soils are significantly greater than the

* K. P. Florenskii, "Preliminary Results from the 1961 Combined Tunguska Meteorite Expedition," Meteoritica, Vol XXIII, Moscow, 1963.

felling moments of trees in moist, riverside soils. Each of the first four conclusions was verified by single tree override tests conducted in the United States and in Thailand. Florenskii's fifth conclusion could neither be confirmed nor denied; however, the magnitude of variation he reported is interesting and is summarized in the following tabulation.

Tree Diameter in.	Average Felling Moment, lb-ft		
	Moist Soil	Dry Soil	Percent Increase
5.9	5,100	8,000	57
7.9	10,800	16,600	54
9.8	20,200	26,700	37
11.8	30,400	39,800	31

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

54. Based on the analysis of the data reported herein, and subject to the limits imposed by these data, the following conclusions are offered:

- a. The maximum horizontal pushbar force required to fail a single standing tree may be predicted from the stem diameter, vehicle speed, and pushbar height (paragraphs 33-36).
- b. The work required to fail a single standing tree may be predicted from the stem diameter (paragraph 38).
- c. The work required to override a single standing tree may be predicted from the stem diameter (paragraph 39).
- d. The average horizontal pushbar force required to fail trees in multiple array may be predicted from the stem diameter (paragraph 46).
- e. The work required to fail trees in multiple array may be predicted from the stem diameter (paragraphs 47-48).
- f. The maximum horizontal pushbar force required to fail a bamboo clump may be predicted from clump diameter (paragraph 43).
- g. The work required to fail a bamboo clump may be predicted from stem diameter (paragraph 44).

Recommendations

55. It is recommended that:

- a. Additional single standing tree override tests be conducted in areas of low soil strength to determine the effect, if any, of soil strength on the force required to uproot a tree.
- b. Additional multiple tree override tests be performed to extend the relations already developed and to develop empirically the relation of work required to override trees in multiple array and stem diameters.
- c. Both single vegetation stem override tests and multiple vegetation stem override tests be conducted in areas of grass and brush to develop override-speed relations.
- d. Additional bamboo override tests be performed in other areas with a vehicle capable of completely overriding the bamboo clumps.

Table B1

Summary of Data and Test Results of Single Tree Override Tests Performed in

Test Vehicle	Site No.*	Test No.	Test Date	Tree No.	Tree Type (Common Name)	Branching Height ft	Tree Height ft	Crown Diameter ft	Stem Diameter 42 In. Aboveground, in.	Work Required to Fall Tree, lb-ft	Work Required to Override Tree, lb-ft	Maximum Tractive Force, lb	Maximum Horizontal Pushbar Force, lb	Maximum Vertical Pushbar Force, lb	Pushbar Height Aboveground in.	Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode of F
															Softwood Trees, United States			
M37	NASA-D	25	Aug 1964	4[illegible]	Pine	2	7	3	1.2	141	**	**	74	**	26	0.0	**	Elastic (st
M37	NASA-C	2	Aug 1964	2	Pine	3	9	3	1.5	178	**	**	57	**	26	0.0	**	Elastic (st
M37	NASA-D	28	Aug 1964	42	Pine	5	11	3	1.6	98	**	**	48	**	26	0.0	**	Elastic (st
M37	E-7	439	May 1964	75	Pine	7	14	5	1.7	447	731	1,317	237	**	26	1.5	0.0	Elastic (st
M37	NASA-C	1	Aug 1964	1	Pine	4	12	4	1.8	339	**	**	155	**	26	0.0	**	Elastic (st
M37	E-7	425	May 1964	60	Pine	1	15	7	1.8	473	703	1,686	226	**	26	1.4	0.0	Elastic (st
M37	NASA-D	24	Aug 1964	44	Pine	1	13	5	2.0	281	**	**	231	**	26	0.0	**	Elastic (st
M37	E-7	438	May 1964	74	Pine	7	14	5	2.0	637	1,378	1,451	302	**	26	1.8	0.1	Elastic (st
M37	NASA-0	26	Aug 1964	40	Pine	6	14	3	2.2	400	**	**	208	**	26	0.0	**	Tension (st
M37	NASA-D	19	Aug 1964	45	Pine	1	13	8	2.3	307	**	**	166	**	26	0.0	**	Elastic (st
M37	E-7	423	May 1964	59	Pine	0.5	16	10	2.5	1,053	1,617	1,928	594	**	26	1.5	0.08	Elastic (st
M37	E-7	432	May 1964	68	Pine	14	18	14	2.6	990	1,396	1,490	505	**	26	1.9	0.09	Elastic (st
M37	C	6	Aug 1964	6	Pine	11	10	6	2.7	1,623	**	**	655	**	26	0.0	**	Compression
M37	NASA-D	20	Aug 1964	38	Pine	7	15	5	2.7	877	**	**	511	**	26	0.0	**	Elastic (st
M37	NASA-C	15	Aug 1964	16	Pine	5	14	8	3.0	1,260	**	**	615	**	26	0.0	**	Elastic (st
M37	E-7	422	May 1964	58	Pine	0.3	20	8	3.0	1,368	1,831	1,912	826	**	26	1.5	0.05	Elastic (st
M37	E-7	431A	May 1964	67	Pine	15	25	4	3.0	1,720	2,177	2,[illegible]24	939	**	26	1.5	0.09	Tension (st
M37	NASA-D	22	Aug 1964	31	Pine	6	19	7	3.2	1,535	**	**	620	**	26	0.0	**	Elastic (st
M37	NASA-D	27	Aug 1964	41	Pine	6	22	6	3.4	2.544	**	**	1,249	**	26	0.0	**	Tension (st
M37	E-7	433	May 1964	69	Pine	4	27	10	3.4	1,676	1,907	2,083	1,183	**	26	1.8	0.12	Shear (soil) Tension (ro
M37	E-7	442	May 1964	78	Pine	7	35	10	3.4	2,657	4,648	2,421	1,456	**	26	1.7	0.11	Tension (st
M37	NASA-C	9	Aug 1964	9	Pine	23	34	5	3.5	2,544	**	**	1,472	**	26	0.0	**	Tension (st
M37	NASA-C	16	Aug 1964	18	Pine	6	13	10	3.5	1,615	**	**	889	**	26	0.0	**	Elastic (st
M37	E-7	424	May 1964	59	Pine	1	22	10	3.5	1,876	2,047	2,179	988	**	26	1.5	0.12	Elastic (st
M37	NASA-C	17	Aug 1964	15	Pine	8	19	10	3.6	2,607	**	**	1,219	**	26	0.0	**	Tension (st
M37	NASA-C	13	Aug 1964	13	Pine	6	24	9	3.9	2,850	**	**	1,163	**	26	0.0	**	Shear (soil) Tension (ro
M37	E-7	437	May 1964	73	Pine	**	**	5	3.9	3,096	3,918	2,285	1,302	**	26	1.7	0.30	Elastic (st
M37	NASA-C	7	Aug 1964	7	Pine	**	31	**	4.0	2,257	**	**	1,436	**	26	0.0	**	Shear (soil) Tension (ro
M113	NASA-B	8	Nov 1964	46	Pine	**	43	12	4.0	†	**	**	1,500	230	56	0.0	**	Tension (ro
M113	NASA-B	9	Nov 1964	47	Pine	16	44	15	4.0	†	**	**	1,150	475	56	0.0	**	Shear (soil) Tension (ro
M37	NASA-C	5	Aug 1964	5	Pine	18	38	10	4.1	3.290	**	**	1,934	**	26	0.0	**	Shear (soil) Tension (ro
M37	NASA-C	12	Aug 1964	12	Pine	7	23	9	4.1	3,207	**	**	1,471	**	26	0.0	**	Tension (st
M113	NASA-E	94	Nov 1964	125	Pine	20	35	7	4.1	†	**	**	2,400	940	38	0.0	**	Tension (st
M37	E-7	427	Kay 1964	62	Pine	2	14	15	4.1	3.392	4,700	1,316	1,780	**	26	1.6	0.32	Shear (soil) Tension (ro
M113	NASA-C	61	Nov 1964	28	Pine	10	26	10	4.1	†	**	**	2,650	900	38	5.7	0.10	Tension (ro
M113	NASA-D	36	Nov 1964	84	Pine	**	28	6	4.2	4,800	**	**	2,550	860	20	0.0	**	Shear (soil) Tension (ro
M113	NASA-A	3	Nov 1964	55	Cypress	8	18	6	4.2	†	**	**	820	270	56	0.0	**	Tension (st
M113	NASA-C	63	Nov 1964	65	Pine	8	20	15	4.2	†	**	**	3,700	1,500	38	7.0	††	Shear (soil) Tension (ro
M113	NASA-A	126	Nov 1964	159	Pine	20	50	10	4.2	†	**	**	2,200	750	38	5.0	0.20	Shear (soil) Tension (ro
M113	NASA-E	21	Nov 1964	3	Pine	8	21	10	4.3	7,600	**	**	3,175	940	20	0.0	**	Shear (soil) Tension (ro
M113	NASA-E	25	Nov 1964	82	Pine	8	23	9	4.3	6,800	**	**	3,525	1,880	20	0.0	**	Compression
M37	E-7	426	May 1964	61	Pine	3	30	16	4.3	5,270	6,528	4,962	2,889	**	26	1.8	0.28	Elartic (st
M113	NASA-A	134	Nov 1964	165	Pine	25	45	15	4.3	†	**	**	3,130	1,380	38	12.2	0.40	Shear (soil) Tension (ro
M113	NASA-0	93	Nov 1964	124	Pine	30	35	7	4.4	†	**	**	2,100	680	38	0.0	**	Shear (soil) Tension (ro
M37	E-7	435	May 1964	71	Pine	20	30	5	4.4	3,952	4,70[illegible]	3,752	2,655	**	26	1.4	0.29	Shear (soil) Tension (ro
M37	NASA-C	8	Aug 1964	8	Pine	17	39	8	4.5	11,277	**	**	4,633	**	26	0.0	**	Compression
M37	NASA-C	11	Aug 1964	37	Pine	12	28	10	4.5	4,078	**	**	2,072	**	26	0.0	**	Tension (st
M113	NASA-C	64	Nov 1964	66	Pine	7	20	9	4.5	†	**	**	4,050	1,320	38	10.3	††	Compression
M113	NASA-A	47	Nov 1964	39	Pine	18	37	10	4.6	†	**	**	2,750	1,050	38	0.0	**	Shear (soil) Tension (ro

(Continued)

* See description of test areas and test sites.
** No measurement made.
† Total work not recorded.
†† Instrumentation failed.

A

Table B1

...e Tree Override Tests Performed in United States and Thailand

Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode of Failure	Average Cone Index 0- to 6-in. Layer	Average Cone Index 6- to 12-in. Layer	Average Cone Index 12- to 18-in. Layer	Average Cone Index 18- to 24-in. Layer	Average Cone Index 24- to 30-in. Layer	USCS Soil Classification 0- to 6-in. Layer	USCS Soil Classification 6- to 12-in. Layer	USCS Soil Classification 12- to 18-in. Layer	Moisture Content, % 0- to 6-in. Layer	Moisture Content, % 6- to 12-in. Layer	Moisture Content, % 12- to 18-in. Layer	Remarks
...wood Trees, United States														
0.0	**	Elastic (stem)	420	640	650	700	750	ML	CL-ML	CL	22.1	18.2	26.9	
0.0	**	Elastic (stem)	202	192	192	282	474	ML	ML	CL	19.2	15.2	16.6	
0.0	**	Elastic (stem)	200	220	300	340	460	ML	CL-ML	CL	22.9	17.9	18.1	
1.5	0.0	Elastic (stem)	89	112	148	241	295	SM	SP-SM	SP-SM	7.7	7.1	7.4	
0.0	**	Elastic (stem)	201	202	192	222	334	ML	ML	CL	15.9	14.8	[illegible]	
1.4	0.0	Elastic (stem)	95	118	104	98	102	SM	SP-SM	SP-SM	3.8	4.4	[illegible]	
0.0	**	Elastic (stem)	330	720	750	750	750	ML	CL-ML	CL	24.5	18.4	21.1	
1.8	0.1	Elastic (stem)	89	112	148	241	295	SM	SP-SM	SP-SM	7.7	7.1	7.4	
0.0	**	Tension (stem)	200	260	230	220	560	ML	CL-ML	CL	25.6	21.0	21.4	
0.0	**	Elastic (stem)	240	330	280	380	520	ML	CL-ML	CL	17.6	15.0	14.9	
1.5	0.08	Elastic (stem)	96	108	98	95	91	SM	SP-SM	SP-SM	3.8	4.4	4.8	
1.9	0.09	Elastic (stem)	124	197	192	167	149	SM	SP-SM	SP-SM	7.7	7.1	7.4	
0.0	**	Compression (stem)	370	470	482	521	575	ML	ML	CL	14.9	15.8	16.9	Stem broke 4 in. above ground surface
0.0	**	Elastic (stem)	140	150	240	330	500	ML	CL-ML	CL	31.2	23.6	25.2	
0.0	**	Elastic (stem)	161	195	159	132	147	ML	ML	CL	28.3	19.5	21.1	
1.5	0.06	Elastic (stem)	104	107	83	89	106	SM	SP-SM	SP-SM	3.8	[illegible]	4.8	
1.5	0.09	Tension (stem)	102	118	139	180	250	SM	SP-SM	SP-SM	7.7	7.1	7.4	
0.0	**	Elastic (stem)	160	120	130	180	260	ML	CL-ML	CL	25.5	21.8	20.9	
0.0	**	Tension (stem)	160	190	280	370	530	ML	CL-ML	CL	23.9	20.2	19.6	
1.8	0.12	Shear (soil) Tension (root)	124	197	192	167	149	SM	SP-SM	SP-SM	7.7	7.1	7.4	
1.7	0.11	Tension (stem)	98	124	145	243	297	SM	SP-SM	SP-SM	7.7	7.1	7.4	
0.0	**	Tension (stem)	136	174	184	261	352	ML	ML	CL	22.0	18.3	19.1	Stem appeared infected 8 in. above ground surface
0.0	**	Elastic (stem)	185	226	181	157	130	ML	ML	CL	29.5	19.8	22.4	
1.5	0.12	Elastic (stem)	132	199	197	167	197	SM	SP-SM	SP-SM	3.8	4.4	4.8	
0.0	**	Tension (stem)	206	241	182	150	175	ML	ML	CL	31.6	19.6	19.6	
0.0	**	Shear (soil) Tension (root)	154	194	214	243	362	ML	ML	CL	33.5	21.0	20.6	
1.7	0.30	Elastic (stem)	101	137	170	229	279	SM	SP-SM	SP-SM	7.7	7.1	7.4	
0.0	**	Shear (soil) Tension (root)	136	140	144	172	281	ML	ML	CL	22.2	20.1	21.0	
0.0	**	Tension (root)	188	303	302	**	**	SC-SM	ML	CL	5.4	6.8	6.8	
0.0	**	Shear (soil) Tension (root)	253	376	351	**	**	SC-SM	ML	CL	5.4	6.8	6.8	Taproot failed 24 in. below ground surface
0.0	**	Shear (soil) Tension (root)	404	418	341	389	435	ML	ML	CL	18.7	16.1	16.9	Entire crown was not overridden due to short departure lane
0.0	**	Tension (stem)	165	180	166	210	376	ML	ML	CL	28.6	20.0	21.2	
0.0	**	Tension (stem)	217	290	287	**	**	ML	ML	CL	15.2	12.1	13.5	Small portion of stem was infected
1.6	0.32	Shear (soil) Tension (root)	83	90	82	99	114	SM	SP-SM	SP-SM	3.8	4.4	4.8	
5.7	0.10	Tension (root)	304	380	370	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
0.0	**	Shear (soil) Tension (root)	282	424	544	**	**	ML	CL	CL	9.6	8.7	11.1	Taproot failed 18 in. below ground surface
0.0	**	Tension (stem)	80	119	127	**	**	ML	CL-ML	CL	28.4	21.3	21.6	Tree appeared to be infected
7.0	††	Shear (soil) Tension (root)	160	196	182	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
5.0	0.20	Shear (soil) Tension (root)	236	300	313	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
0.0	**	Shear (soil) Tension (root)	176	270	294	**	**	ML	ML	CL	11.8	10.6	11.7	Taproot did not rupture
0.0	**	Compression (stem)	230	250	234	**	**	ML	ML	CL	21.2	15.2	15.6	
1.8	0.28	Elastic (stem)	110	109	89	90	89	SM	SP-SM	SP-SM	3.8	4.4	4.8	
12.2	0.40	Shear (soil) Tension (root)	290	519	545	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
0.0	**	Shear (soil) Tension (root)	245	320	297	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 18 in. below ground surface
1.4	0.29	Shear (soil) Tension (root)	77	101	149	207	247	SM	SP-SM	SP-SM	7.7	7.1	7.4	
0.0	**	Compression (stem)	206	365	393	426	461	ML	ML	CL	23.0	49.3	20.2	Complete crown was not overridden due to short departure lane
0.0	**	Tension (stem)	165	179	163	183	215	ML	ML	CL	16.9	14.3	14.3	
10.3	††	Compression (stem)	256	280	174	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
0.0	**	Shear (soil) Tension (root)	168	212	262	**	**	ML	CL-ML	CL	17.8	17.3	18.7	

(Continued)

(1 of 8 sheets)

B

Test Vehicle	Site No.	Test No.	Test Date	Tree No.	Tree Type (Common Name)	Branching Height ft	Tree Height ft	Crown Diameter ft	Stem Diameter 1/2 in. Aboveground, in.	Work Required to Fell Tree, lb-ft	Work Required to Override Tree, lb-ft	Maximum Tractive Force, lb	Maximum Horizontal Pushbar Force, lb	Maximum Vertical Pushbar Force, lb	Pushbar Height Aboveground in.	Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode of
															Softwood Trees, United States (Continued)			
M113	NASA-A	56	Nov 1964	95	Pine	20	**	10	4.6	†	**	**	2,450	1,020	38	0.0	**	Tension (
M113	NASA-A	53	Nov 1964	92	Pine	20	35	15	4.6	†	**	**	4,050	1,500	38	6.4	††	Tension (
M113	NASA-C	72	Nov 1964	103	Pine	10	20	12	4.6	†	**	**	**	**	38	12.7	**	Elastic (
M113	NASA-A	132	Nov 1964	163	Pine	20	36	10	4.6	†	**	**	3,400	1,160	38	13.3	0.40	Shear (sof Tension (
M113	NASA-A	57	Nov 1964	96	Pine	13	32	15	4.7	†	**	**	2,400	670	38	0.0	**	Shear (sof Tension (
M113	NASA-A	42	Nov 1964	88	Pine	25	39	7	4.7	†	**	**	3,200	1,000	38	12.4	0.10	Shear (sof Tension (
M113	NASA-E	82	Nov 1964	113	Pine	12	28	10	4.7	†	**	**	3,100	600	38	4.4	††	Shear (sof Tension (
M113	NASA-A	124	Nov 1964	155	Pine	25	33	5	4.7	†	**	**	**	**	38	10.8	0.10	Tension (
M37	NASA-C	14	Aug 1964	14	Pine	9	23	9	4.8	4,816	**	**	2,025	**	26	0.0	**	Tension (
M113	NASA-A	121	Nov 1964	152	Pine	30	39	10	4.8	†	**	**	4,600	600	38	12.9	0.30	Shear (sof Tension (
M113	NASA-E	26	Nov 1964	83	Pine	**	27	10	4.9	6,080	**	**	3,500	850	20	6.0	**	Shear (sof Tension (
M37	E-7	430	May 1964	65	Pine	4	27	9	4.9	2,854	3,990	3,390	1,773	**	26	1.5	0.18	Shear (sof Tension (
M113	NASA-C	68	Nov 1964	99	Pine	7	30	10	4.9	†	**	**	5,750	2,000	38	11.1	††	Shear (sof Tension (
M113	NASA-E	81	Nov 1964	112	Pine	20	31	9	4.9	†	**	**	3,300	1,400	38	7.0	††	Shear (sof Tension (
M113	NASA-A	119	Nov 1964	150	Pine	24	40	5	4.9	†	**	**	4,300	1,000	38	13.7	0.50	Shear (sof Tension (
M37	NASA-D	21	Aug 1964	32	Pine	6	27	10	5.0	11,166	**	**	3,886	**	26	0.0	**	Tension (
M113	NASA-B	10	Nov 1964	48	Pine	**	44	**	5.0	†	**	**	1,825	910	56	0.0	**	Shear (sof Tension (
M113	NASA-E	91	Nov 1964	122	Pine	15	25	12	5.0	†	**	**	2,550	1,500	38	1.0	**	Shear (sof Tension (
M37	E-7	434	May 1964	70	Pine	20	38	11	5.0	7,784	10,405	5,770	3,685	**	26	1.4	0.43	Shear (sof Tension (
M37	E-7	440	May 1964	76	Pine	24	32	9	5.0	5,077	6,290	3,888	2,386	**	26	2.2	0.37	Shear (sof Tension (
M113	NASA-A	55	Nov 1964	94	Pine	30	44	10	5.0	†	**	**	4,100	1,150	38	4.3	0.10	Shear (sof Tension (
M113	NASA-C	60	Nov 1964	29	Pine	7	27	15	5.0	†	**	**	3,800	550	38	4.9	0.30	Shear (so Tension (
M113	NASA-C	73	Nov 1964	104	Pine	6	27	12	5.0	†	**	**	3,650	950	38	14.0	††	Shear (so Tension (
M113	NASA-E	78	Nov 1964	109	Pine	10	24	9	5.0	†	**	**	**	**	38	14.8	††	Shear (so Tension (
M113	NASA-E	85	Nov 1964	116	Pine	21	39	8	5.0	†	**	**	**	**	38	10.3	††	Tension (
M113	NASA-A	111	Nov 1964	142	Pine	8	37	10	5.0	†	**	**	5,150	2,000	38	6.1	0.20	Elastic (
M113	NASA-B	17	Nov 1964	17	Pine	10	36	15	5.1	10,400	**	**	5,375	2,400	20	0.0	**	Shear (so Tension (
M113	NASA-E	22	Nov 1964	4	Pine	8	30	14	5.1	13,440	**	**	4,100	1,400	20	0.0	**	Shear (so Tension (
M113	NASA-A	136	Nov 1964	167	Pine	15	37	15	5.1	†	**	**	4,200	975	38	††	††	Shear (so Tension (
M113	NASA-C	70	Nov 1964	101	Pine	15	33	10	5.2	†	**	**	7,050	1,550	38	10.6	††	Shear (so Tension (
M113	NASA-C	71	Nov 1964	102	Pine	9	27	13	5.2	†	**	**	4,900	1,600	38	11.1	††	Shear (so Tension (
M113	NASA-C	74	Nov 1964	105	Pine	21	33	8	5.2	†	**	**	6,400	1,550	38	5.9	††	Shear (so Tension (
M113	NASA-C	76	Nov 1964	107	Pine	8	22	15	5.2	†	**	**	5,100	1,100	38	8.1	††	Shear (so Tension (
M113	NASA-C	77	Nov 1964	108	Pine	[illegible]	39	15	5.2	†	**	**	††	††	38	8.1	††	Shear (so Tension (
M113	NASA-A	140	Nov 1964	171	Pine	14	33	10	5.2	†	**	**	4,400	1,100	38	4.6	0.25	Shear (so Tension (
M113	NASA-A	141	Nov 1964	172	Pine	24	39	8	[illegible]	†	**	**	4,800	1,300	38	[illegible]	0.40	Shear (so Tension (
M37	NASA-C	4	Aug 1964	4	Pine	[illegible]	37	10	5.3	22,400	**	**	4,256	**	26	0.0	**	Tension (
M37	NASA-D	23	[illegible] 1964	28	Pine	6	22	10	5.3	5,401	**	**	2,887	**	26	0.0	**	Shear (so Tension (
M113	NASA-B	18	Nov 1964	77	Pine	105	30	[illegible]	5.3	7,760	**	**	4,550	1,050	20	0.0	**	Shear (so Tension (
M113	NASA-E	86	Nov 1964	117	Pine	10	36	15	5.3	†	**	**	4,200	2,300	38	0.0	**	Elastic (

(Continued)

** No measurement made.
† Total work not recorded.
†† Instrumentation failed.

A

ble B1 (Continued)

Maximum Longitudinal Acceleration g	Mode of Failure	Average Cone Index 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	18- to 24-in. Layer	24- to 30-in. Layer	USCS Soil Classification 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	Moisture Content, % 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	Remarks
United States (Continued)													
**	Tension (stem)	268	401	381	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
††	Tension (stem)	188	273	315	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
**	Elastic (stem)	263	324	344	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
0.40	Shear (soil) Tension (root)	350	563	554	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
**	Shear (soil) Tension (root)	136	220	270	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
0.10	Shear (soil) Tension (root)	280	335	282	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 12 in. above ground surface
††	Shear (soil) Tension (root)	204	275	269	**	**	ML	ML	CL	15.0	12.1	13.5	
0.10	Tension (stem)	269	383	402	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
**	Tension (stem)	151	155	144	217	420	ML	ML	CL	31.5	20.7	22.0	
0.30	Shear (soil) Tension (root)	366	498	497	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
**	Shear (soil) Tension (root)	247	283	184	**	**	ML	ML	CL	21.2	15.2	15.6	Infected area observed on stem just above ground surface. Taproot failed 12 in. below ground surface
0.18	Shear (soil) Tension (root)	119	153	107	186	81	SM	SP-SM	SP-SM	3.8	4.4	4.8	
††	Shear (soil) Tension (root)	228	259	338	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
††	Shear (soil) Tension (root)	195	311	394	**	**	ML	ML	CL	15.0	12.1	13.5	
0.50	Shear (soil) Tension (root)	285	341	294	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
**	Tension (stem)	210	220	200	260	390	ML	CL-ML	CL	13.7	12.9	14.2	
**	Shear (soil) Tension (root)	270	[illegible]	325	**	**	SC-SM	ML	CL	5.4	6.8	6.8	
**	Shear (soil) Tension (root)	178	291	286	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 6 in. below ground surface
0.43	Shear (soil) Tension (root)	77	101	149	207	247	SM	SP-SM	SP-SM	7.7	7.1	7.4	
0.37	Shear (soil) Tension (root)	91	124	137	203	273	SM	SP-SM	SP-SM	7.7	7.1	7.4	
0.10	Shear (soil) Tension (root)	331	471	459	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
0.30	Shear (soil) Tension (root)	396	488	422	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	Taproot failed 10 in. below ground surface
††	Shear (soil) Tension (root)	337	317	407	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
††	Shear (soil) Tension (root)	517	750	750	**	**	ML	ML	CL	15.0	12.1	13.5	
††	Tension (stem)	185	250	359	**	**	ML	ML	CL	15.0	12.1	13.5	
0.20	Elastic (stem)	533	750	750	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
**	Shear (soil) Tension (root)	302	381	351	**	**	SC-SM	ML	CL	13.2	11.0	11.7	
**	Shear (soil) Tension (root)	183	246	274	**	**	ML	ML	CL	14.1	12.1	12.8	Taproot failed 18 in. below ground surface
††	Shear (soil) Tension (root)	351	530	590	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Tree failed 22 ft above ground surface
††	Shear (soil) Tension (root)	184	186	264	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
††	Shear (soil) Tension (root)	195	214	251	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
††	Shear (soil) Tension (root)	217	333	394	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
††	Shear (soil) Tension (root)	170	217	221	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
††	Shear (soil) Tension (root)	520	750	750	**	**	CL-ML	CL-ML	CL	15.0	12.1	13.5	
0.25	Shear (soil) Tension (root)	221	297	328	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
0.40	Shear (soil) Tension (root)	371	513	520	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
**	Tension (stem)	396	433	421	432	454	ML	ML	CL	16.0	16.1	16.7	Undercarriage of vehicle scraped bark and wood from tree stem
**	Shear (soil) Tension (root)	190	200	160	200	280	ML	CL-ML	CL	21.0	15.8	19.9	
**	Shear (soil) Tension (root)	178	217	264	**	**	SC-SM	ML	CL	[illegible]	[illegible]	16.7	Taproot failed [illegible] in. below ground surface
**	Elastic (stem)	324	369	337	**	**	ML	ML	CL	15.0	12.1	13.5	

tinued)

(of sheets)

B

Test Vehicle	Site No.	Test No.	Test Date	Tree No.	Tree Type or Name	Branching Height ft	Tree Height ft	Crown Diameter ft	Stem Diameter 4.5 ft Above Ground, in.	Work Required to Fail Tree, lb-ft	Work Required to Override Tree, lb-ft	Maximum Tractive Force, lb	Maximum Horizontal Pushbar Force, lb	Maximum Vertical Pushbar Force, lb	Pushbar Height Above Ground in.	Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode of F
															Isolated Trees, United States (Continued)			
M113	NASA-A	49	Nov [illegible]	[illegible]	Pine	[illegible]	44	10	5.3	†	**	**	4,750	1,150	[illegible]	4.0	0.35	Shear (soil Tension (r
M113	NASA-C	67	Nov [illegible]	[illegible]	Pine	[illegible]	[illegible]	12	5.3	†	**	**	10,200	[illegible],100	[illegible]	16.[illegible]	††	Shear (soil Tension (ro
M113	NASA-E	156	Nov 1964	187	Pine	[illegible]	41	12	5.4	†	**	**	4,800	1,400	38	[illegible].0	**	Shear (soil Tension (ro
M113	NASA-A	129	Nov 1964	[illegible]	Pine	[illegible]	36	10	5.4	†	**	**	[illegible]	2,300	[illegible]	13.1	0.45	Tension (st
M113	NASA-A	142	Nov 1964	173	Pine	[illegible]	39	10	5.4	†	**	**	3,650	[illegible]	38	3.9	0.45	Shear (soil Tension (ro
M113	NASA-A	58	Nov 1964	[illegible]	Pine	[illegible]	40	10	5.5	†	**	**	6,900	5,050	38	4.0	0.40	Elastic (st
M113	NASA-A	130	Nov 1964	[illegible]	Pine	[illegible]	40	15	5.5	†	**	**	8,600	[illegible]50	38	12.9	0.50	Tension (st
M113	NASA-A	131	Nov 1964	162	Pine	[illegible]	35	10	5.5	†	**	**	4,500	1,100	38	13.1	††	Shear (soil Tension (ro
M113	NASA-A	133	Nov 1964	164	Pine	[illegible]	48	10	5.5	†	**	**	5,680	[illegible],500	38	10.2	0.50	Elastic (st
M37	E-7	431	May 1964	66	Pine	[illegible]	40	20	5.6	9,625	15,606	5,154	5,192	**	26	1.4	-0.85	Shear (soil, Tension (ro
M37	E-7	441	May 1964	77	Pine	[illegible]	40	17	5.5	18,782	23,960	4,447	4,973	**	26	3.9	-0.85	Shear (soil) Tension (ro
M113	NASA-A	116	Nov 1964	147	Pine	[illegible]	44	8	5.6	†	**	**	5,600	1,200	38	13.1	0.60	Shear (soil) Tension (ro
M113	NASA-E	79	Nov 1964	110	Pine	[illegible]	41	10	5.7	†	**	**	††	††	38	0.0	**	Shear (soil) Tension (ro
M37	E-7	436	May 1964	72	Pine	15	40	8	5.7	††	††	5,251	††	**	26	1.7	-0.90	No Failure
M37	E-7	429	May 1964	64	Pine	4	38	20	5.8	††	††	4,729	††	**	26	1.9	-0.70	No Failure
M113	NASA-C	75	Nov 1964	106	Pine	8	24	14	5.8	†	**	**	7,300	1,550	38	5.9	††	Shear (soil) Tension (ro
M113	NASA-A	117	Nov 1964	149	Pine	30	42	9	5.8	†	**	**	††	1,400	38	11.4	0.70	Shear (soil) Tension (ro
M37	E-7	428	May 1964	63	Pine	5	40	20	5.9	††	††	5,623	††	**	26	1.7	-1.14	No Failure
M113	NASA-A	120	Nov 1964	151	Pine	18	--	12	5.9	†	**	**	7,550	1,740	38	17.1	0.90	Shear (soil) Tension (ro
M113	NASA-E	150	Nov 1964	181	Pine	35	51	8	6.0	22,320	**	**	7,650	3,650	20	0.0	**	Elastic (ste
M113	NASA-E	83	Nov 1964	114	Pine	40	48	15	6.0	†	**	**	††	††	38	9.1	††	Shear (soil) Tension (ro
M113	NASA-A	112	Nov 1964	143	Pine	25	48	12	6.0	†	**	**	8,300	2,100	38	6.1	0.40	Shear (soil) Tension (ro
M113	NASA-B	16	Nov 1964	12	Pine	15	35	23	6.1	27,920	**	**	10,850	2,925	20	0.0	**	Shear (soil) Tension (ro
M113	NASA-E	80	Nov 1964	111	Pine	20	42	10	6.1	†	**	**	7,250	2,300	38	12.5	††	Shear (soil) Tension (ro
M113	NASA-A	115	Nov 1964	146	Pine	24	45	15	6.1	†	**	**	6,800	1,975	38	11.3	0.80	Shear (soil) Tension (ro
M113	NASA-E	84	Nov 1964	115	Pine	18	47	7	6.2	†	**	**	9,300	2,600	38	5.1	††	Elastic (ste
M113	NASA-A	125	Nov 1964	156	Pine	40	55	15	6.2	†	**	**	6,750	1,650	38	12.2	0.60	Shear (soil) Tension (ro
M113	NASA-E	90	Nov 1964	121	Pine	16	35	19	6.3	†	**	**	††	††	38	13.7	††	Shear (soil) Tension (ro
M113	NASA-B	20	Nov 1964	79	Pine	14	36	11	6.4	16,560	**	**	9,450	2,000	20	0.0	**	Shear (soil) Tension (ro
M113	NASA-[illegible]	32	Nov 1964	19	Pine	20	45	10	6.4	23,520	**	**	13,900	5,800	20	0.0	**	Shear (soil) Tension (ro
M113	NASA-[illegible]	44	Nov 1964	90	Pine	30	50	20	6.4	†	**	**	9,200	2,300	38	5.2	††	Shear (soil) Tension (ro
M113	NASA-A	139	Nov 1964	170	Pine	30	54	5	6.5	†	**	**	9,500	2,375	38	6.3	0.70	Shear (soil) Tension (ro
M113	NASA-A	145	Nov 1964	174	Pine	24	37	12	6.5	†	**	**	7,600	2,450	38	4.8	0.40	Shear (soil) Tension (ro
M113	NASA-D	38	Nov 1964	71	Pine	15	30	12	6.6	23,440	**	**	8,050	4,350	20	0.0	**	Tension (st
M113	NASA-A	4	Nov 1964	59	Pine	12	42	18	6.6	†	**	**	3,700	1,850	56	0.0	**	Shear (soil) Tension (ro
M113	NASA-C	69	Nov 1964	100	Pine	15	27	15	6.6	†	**	**	5,800	1,900	38	0.0	**	Shear (soil) Tension (ro
M113	NASA-C	65	Nov 1964	67	Pine	12	33	12	6.6	†	**	**	††	††	38	6.3	††	Shear (soil) Tension (ro
M113	NASA-E	104	Nov 1964	135	Pine	14	45	20	6.6	†	**	**	10,700	2,300	38	9.0	††	Shear (soil) Tension (ro
M113	NASA-E	106	Nov 1964	137	Pine	30	48	10	6.6	†	**	**	9,650	2,000	38	8.4	††	Shear (soil) Tension (ro
M113	NASA-E	108	Nov 1964	139	Pine	30	40	10	6.6	†	**	**	9.500	1,950	38	3.7	††	Shear (soil) Tension (ro
M113	NASA-A	137	Nov 1964	168	Pine	20	49	20	6.6	†	**	**	8,800	1,500	38	12.6	0.60	Shear (soil) Tension (ro

(Continued)

** No measurement made.
† Total work not recorded.
†† Instrumentation failed.

A

Table B1 (Continued)

ed act h	Maximum Longitudinal Acceleration g	Mode of Failure	Average Cone Index 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	18- to 24-in. Layer	24- to 30-in. Layer	USCS Soil Classification 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	Moisture Content, % 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	Remarks
s, United States (Continued)														
0	0.35	Shear (soil) Tension (root)	215	285	333	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 18 in. below ground surface
2	††	Shear (soil) Tension (root)	201	239	261	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
0	**	Shear (soil) Tension (root)	118	112	185	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed at ground surface
1	0.45	Tension (stem)	218	349	381	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Stem failed in tension 6 in. above ground surface
9	0.45	Shear (soil) Tension (root)	238	368	316	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 18 in. below ground surface. Main stem failed 24 ft above ground surface
5	0.40	Elastic (stem)	519	750	750	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
9	0.50	Tension (stem)	200	297	292	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Tree failed in tension 8 ft above ground surface
1	††	Shear (soil) Tension (root)	299	477	572	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Main stem failed 25 ft above ground surface
2	0.50	Elastic (stem)	360	614	640	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
	-0.85	Shear (soil) Tension (root)	124	197	192	167	149	SM	SP-SM	SP-SM	3.8	4.4	4.8	
	-0.85	Shear (soil) Tension (root)	97	135	160	205	293	SM	SP-SM	SP-SM	7.7	7.1	7.4	
	0.60	Shear (soil) Tension (root)	234	362	414	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
	**	Shear (soil) Tension (root)	367	472	517	**	**	ML	ML	CL	15.0	12.1	13.5	Portion of stem was infected from the ground surface to a height of 24 in.
	-0.90	No Failure	90	120	150	237	298	SM	SP-SM	SP-SM	7.7	7.1	7.4	Vehicle immobilized
	-0.70	No Failure	102	133	139	115	113	SM	SP-SM	SP-SM	3.8	4.4	4.8	Vehicle immobilized
	††	Shear (soil) Tension (root)	332	519	480	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	Infected taproot. Taproot failed 20 in. below ground surface
	0.70	Shear (soil) Tension (root)	378	491	441	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
	-1.14	No Failure	117	132	106	85	67	SM	SP-SM	SP-SM	3.8	4.4	4.8	Vehicle immobilized
	0.90	Shear (soil) Tension (root)	327	370	314	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Stem was snapped off at the pushbar height of 38 in. and fell on top of the vehicle
	**	Elastic (stem)	396	527	534	**	**	ML	ML	CL	15.0	12.1	13.5	
	††	Shear (soil) Tension (root)	307	362	275	**	**	ML	ML	CL	15.0	12.1	13.5	
	0.40	Shear (soil) Tension (root)	265	437	552	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
	**	Shear (soil) Tension (root)	183	256	259	**	**	SC-SM	ML	CL	13.8	13.1	13.9	Undercarriage of vehicle dragged on the exposed root bulb
	††	Shear (soil) Tension (root)	265	359	388	**	**	ML	ML	CL	15.0	12.1	13.5	
	0.80	Shear (soil) Tension (root)	508	750	750	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
	††	Elastic (stem)	401	474	545	**	**	ML	ML	CL	15.0	12.1	13.5	
	0.60	Shear (soil) Tension (root)	349	596	645	**	**	ML	CL-ML	CL	17.8	17.3	13.9	Taproot failed 18 in. below ground surface
	††	Shear (soil) Tension (root)	212	291	345	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 18 in. below ground surface. Stem assumed a bow shape immediately after contact
	**	Shear (soil) Tension (root)	293	310	340	**	**	SC-SM	ML	CL	10.6	9.5	12.4	Taproot failed 30 in. below ground surface
	**	Shear (soil) Tension (root)	246	326	319	**	**	ML	CL	CL	18.6	15.3	14.8	Taproot failed 24 in. below ground surface
	††	Shear (soil) Tension (root)	335	415	333	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed [illegible] in. below ground surface
	0.70	Shear (soil) Tension (root)	386	502	464	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 6 in. below ground surface
	0.40	Shear (soil) Tension (root)	214	257	253	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 18 in. below ground surface
	**	Tension (stem)	294	493	492	**	**	ML	CL	CL	18.5	12.7	13.2	Stem fell against a neighboring tree before contacting the ground
	**	Shear (soil) Tension (root)	327	374	423	**	**	ML	CL-ML	CL	12.9	20.1	22.7	
	**	Shear (soil) Tension (root)	190	236	316	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
	††	Shear (soil) Tension (root)	205	315	376	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	
	††	Shear (soil) Tension (root)	183	279	305	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 30 in. below ground surface
	††	Shear (soil) Tension (root)	236	374	531	**	**	ML	ML	CL	15.0	12.1	13.5	Tree crown failed 28 ft above ground surface
	††	Shear (soil) Tension (root)	136	222	311	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 36 in. below ground surface
	0.60	Shear (soil) Tension (root)	326	676	682	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Stem failed in tension 6 ft above ground surface

(Continued)

(3 of 8 sheets)

B

Table B1 (Continued)

Test Vehicle	Site No.	Test No.	Test Date	Tree No.	Tree Type (Common Name)	Branching Height ft	Tree Height ft	Crown Diameter ft	Stem Diameter 42 in. Aboveground, in.	Work Required to Fall Tree, lb-ft	Work Required to Override Tree, lb-ft	Maximum Tractive Force, lb	Maximum Horizontal Pushbar Force, lb	Maximum Vertical Pushbar Force, lb	Pushbar Height Aboveground in.	Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode
															Softwood Trees, United States (Continue			
M113	NASA-D	37	Nov 1964	70	Pine	20	[illegible]	10	6.7	††	**	**	††	††	20	0.0	**	Shear (Tension
M113	NASA-E	107	Nov 1964	138	Pine	15	45	20	6.7	†	**	**	8,550	2,700	38	4.7	††	Shear (Tension
M113	NASA-A	122	Nov 1964	153	Pine	25	47	15	6.7	†	**	**	8,000	2,300	38	8.7	1.00	Shear (Tension
M113	NASA-E	88	Nov 1964	119	Pine	15	32	25	6.8	†	**	**	††	††	38	14.2	††	Shear (Tension
M113	NASA-A	118	Nov 1964	148	Pine	24	58	12	6.8	†	**	**	9,450	2,550	38	5.7	1.10	Shear (Tension
M113	NASA-E	146	Nov 1964	177	Pine	30	46	15	6.9	20,960	**	**	8,800	1,975	20	0.0	**	Shear (Tension
M113	NASA-A	46	Nov 1964	40	Pine	30	50	15	6.9	†	**	**	8,050	2,400	38	0.0	**	Shear (Tension
M113	NASA-C	66	Nov 1964	72	Pine	7	33	17	6.9	†	**	**	6,100	3,250	38	0.0	**	Shear (Tension
M113	NASA-E	102	Nov 1964	133	Pine	15	42	25	6.9	†	**	**	15,200	3,300	38	8.5	††	Shear (Tension
M113	NASA-A	135	Nov 1964	166	Pine	20	45	20	6.9	†	**	**	8,100	2,600	38	12.8	0.90	Shear (Tension
M113	NASA-A	143	Nov 1964	175	Pine	24	45	12	6.9	†	**	**	7,800	2,000	38	11.9	0.50	Shear (Tension
M113	NASA-E	28	Nov 1964	1	Pine	15	32	18	7.0	22,560	**	**	12,000	2,700	20	0.0	**	Shear (Tension
M113	NASA-C	62	Nov 1964	63	Pine	13	30	15	7.0	†	**	**	10,700	2,700	38	4.7	0.40	Shear (Tension
M113	NASA-E	92	Nov 1964	123	Pine	35	45	14	7.0	†	**	**	18,400	3,700	38	14.0	††	Shear (Tension
M113	NASA-E	95	Nov 1964	126	Pine	15	46	20	7.0	†	**	**	††	††	38	10.6	††	Shear (Tension
M113	NASA-E	103	Nov 1964	134	Pine	15	43	25	7.0	†	**	**	15,550	2,850	38	12.7	††	Shear (Tension
M113	NASA-A	110	Nov 1964	141	Pine	24	52	15	7.0	†	**	**	10,800	††	38	14.6	0.75	Shear (Tension
M113	NASA-E	23	Nov 1964	80	Pine	--	67	21	7.1	40,320	**	**	15,300	3,800	[illegible]	0.0	**	Shear (Tension
M113	NASA-E	147	Nov 1964	178	Pine	25	40	12	7.1	22,560	**	**	12,200	1,780	20	0.0	**	Shear (Tension
M113	NASA-D	35	Nov 1964	25	Pine	15	42	20	7.2	21,600	**	**	9,900	2,275	20	0.0	**	Shear (Tension
M113	NASA-D	30	Nov 1964	17	Pine	20	50	25	7.3	33,400	**	**	15,600	5,800	20	0.0	0.01	Tension
M113	NASA-A	48	Nov 1964	38	Pine	30	48	20	7.3	†	**	**	9,600	2,100	38	0.0	**	Shear (Tension
M113	NASA-E	96	Nov 1964	127	Pine	30	40	13	7.4	†	**	**	9,500	2,400	38	0.0	**	Shear (Tension
M113	NASA-E	99	Nov 1964	130	Pine	18	38	30	7.4	†	**	**	††	††	38	0.0	**	Tension
M113	NASA-E	157	Nov 1964	188	Pine	24	55	12	7.4	†	**	**	7,300	1,525	38	0.0	**	Shear (Tension
M113	NASA-B	13	Nov 1964	40	Pine	40	57	15	7.5	†	**	**	7,600	2,100	56	0.0	**	Shear (Tension
M113	NASA-E	97	Nov 1965	128	Pine	20	[illegible]	25	7.5	†	**	**	19,900	4,500	38	10.3	††	Shear (Tension
M113	NASA-A	128	Nov 1965	158	Pine	30	60	10	7.5	†	**	**	13,100	1,100	38	13.1	1.25	Shear (Tension
M113	NASA-D	31	Nov 1964	18	Pine	18	45	20	7.6	36,320	**	**	14,100	3,750	20	0.0	**	Shear (Tension
M113	NASA-E	148	Nov 1964	179	Pine	32	51	16	7.6	36,560	**	**	17,550	2,000	20	0.0	0.25	Shear (Tension
M113	NASA-E	87	Nov 1964	118	Pine	16	45	35	7.6	†	**	**	††	††	38	5.8	††	Shear (Tension
M113	NASA-E	105	Nov 1964	136	Pine	20	45	25	7.6	†	**	**	11,200	2,800	38	7.7	††	Shear (Tension
M113	NASA-A	113	Nov 1964	144	Pine	30	60	18	7.6	†	**	**	12,200	2,150	38	5.7	0.80	Shear (Tension
M113	NASA-E	89	Nov 1964	120	Pine	15	32	25	7.6	†	**	**	††	††	38	8.5	††	Shear (Tension
M113	NASA-A	123	Nov 1964	154	Pine	38	51	16	7.6	†	**	**	13,000	4,300	38	12.0	1.20	Shear (Tension
M113	NASA-E	100	Nov 1964	131	Pine	35	48	30	7.7	†	**	**	18,700	3,200	38	11.2	††	Shear (Tension
M113	NASA-E	109	Nov 1964	140	Pine	20	52	20	7.8	†	**	**	16,100	4,200	38	12.2	††	Shear (Tension
M113	NASA-A	127	Nov 1964	157	Pine	25	57	15	7.8	†	**	**	17,150	-1,950	38	10.8	1.30	Tension

(Continued)

** No measurement made.
† Total work not recorded.
†† Instrumentation failed.

A

Table B1 (Continued)

ed act h	Maximum Longitudinal Acceleration g	Mode of Failure	Average Cone Index 0- to 6-in. Layer	Average Cone Index 6- to 12-in. Layer	Average Cone Index 12- to 18-in. Layer	Average Cone Index 18- to 24-in. Layer	Average Cone Index 24- to 30-in. Layer	USCS Soil Classification 0- to 6-in. Layer	USCS Soil Classification 6- to 12-in. Layer	USCS Soil Classification 12- to 18-in. Layer	Moisture Content, % 0- to 6-in. Layer	Moisture Content, % 6- to 12-in. Layer	Moisture Content, % 12- to 18-in. Layer	Remarks
es, United States (Continued)														
0	**	Shear (soil) Tension (root)	286	446	569	**	**	ML	CL	CL	9.6	8.7	11.1	Taproot failed 30 in. below ground surface
7	††	Shear (soil) Tension (root)	128	135	210	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 24 in. below ground surface
7	1.00	Shear (soil) Tension (root)	297	403	353	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 18 in. below ground surface
2	††	Shear (soil) Tension (root)	218	366	451	**	**	ML	ML	CL	15.0	12.1	13.5	
7	1.10	Shear (soil) Tension (root)	35[illegible]	507	495	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
0	**	Shear (soil) Tension (root)	301	341	298	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 36 in. below ground surface
0	**	Shear (soil) Tension (root)	181	313	393	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
0	**	Shear (soil) Tension (root)	306	350	310	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	Taproot failed 12 in. below ground surface
	††	Shear (soil) Tension (root)	197	232	260	**	**	ML	ML	CL	15.0	12.1	13.5	
	0.90	Shear (soil) Tension (root)	461	660	651	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
	0.50	Shear (soil) Tension (root)	261	364	372	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 30 in. below ground surface. Main stem failed 36 ft above ground surface
	**	Shear (soil) Tension (root)	277	358	280	**	**	ML	ML	CL	13.5	11.4	14.1	Taproot failed 36 in. below ground surface
	0.40	Shear (soil) Tension (root)	181	181	233	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	Taproot failed 24 in. below ground surface
	††	Shear (soil) Tension (root)	213	314	376	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 12 in. below ground surface
	††	Shear (soil) Tension (root)	193	269	237	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 48 in. below ground surface
	††	Shear (soil) Tension (root)	194	254	244	**	**	ML	ML	[illegible]	15.0	12.1	13.5	Taproot failed 24 in. below ground surface. Main stem failed 32 ft above ground surface
	0.75	Shear (soil) Tension (root)	517	750	750	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Stem was snapped off at the pushbar height of 38 in. and fell on [illegible] of vehicle
	**	Shear (soil) Tension (root)	241	322	43[illegible]	**	**	ML	ML	CL	14.0	11.4	10.2	Taproot failed 24 in. below ground surface
	**	Shear (soil) Tension (root)	234	359	45[illegible]	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 24 in. below ground surface
	**	Shear (soil) Tension (root)	125	151	236	**	**	ML	CL	CL	12.5	10.7	13.7	Taproot failed 24 in. below ground surface
	0.01	Tension (stem)	329	553	598	**	**	ML	CL	CL	18.6	15.3	14.8	
	**	Shear (soil) Tension (root)	220	326	380	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 36 in. below ground surface
	**	Shear (soil) Tension (root)	186	323	390	**	**	ML	ML	CL	15.0	12.1	13.5	Front of tracks raised about 6 in. off the ground
	**	Tension (stem)	225	281	263	**	**	ML	ML	CL	15.0	12.1	13.5	A portion of the main stem was infected
	**	Shear (soil) Tension (root)	166	172	300	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 12 in. below ground surface
	**	Shear (soil) Tension (root)	221	365	456	**	**	SC-SM	ML	CL	6.8	6.1	7.9	
	††	Shear (soil) Tension (root)	330	516	580	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 48 in. below ground surface
	1.25	Shear (soil) Tension (root)	291	380	424	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Tree failed at pushbar height and fell on top of vehicle
	**	Shear (soil) Tension (root)	213	215	200	**	**	ML	CL	CL	18.6	15.3	14.8	Taproot failed 12 in. below ground surface
	0.25	Shear (soil) Tension (root)	196	260	385	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 18 in. below ground surface
	††	Shear (soil) Tension (root)	210	282	339	**	**	ML	ML	CL	15.0	12.1	13.5	
	††	Shear (soil) Tension (root)	154	230	317	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 12 in. below ground surface. Main stem failed about 40 ft above ground surface
	0.80	Shear (soil) Tension (root)	261	386	492	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
	††	Shear (soil) Tension (root)	174	373	[illegible]	**	**	ML	ML	CL	15.0	12.1	13.5	
	1.20	Shear (soil) Tension (root)	239	331	373	**	**	ML	CL-ML	CL	17.8	17.3	18.8	Taproot failed 8 in. below ground surface
	††	Shear (soil) Tension (root)	205	335	477	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 20 in. below ground surface. Main stem failed about 35 ft above ground surface
	††	Shear (soil) Tension (root)	339	374	336	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 48 in. below ground surface
	1.30	Tension (stem)	355	621	675	**	**	ML	CL-ML	CL	17.8	17.3	18.8	Stem snapped off at the pushbar height of 38 in. and fell on top of vehicle

(Continued)

(4 of 8 sheets)

B

Test Vehicle	Site No.	Test No.	Test Date	Tree No.	Tree Type (Common Name)	Branching Height ft	Tree Height ft	Crown Diameter ft	Stem Diameter 42 in. Above-ground, in.	Work Required to Fell Tree, lb-ft	Work Required to Override Tree, lb-ft	Maximum Tractive Force, lb	Maximum Horizontal Pushbar Force, lb	Maximum Vertical Pushbar Force, lb	Pushbar Height Above-ground in.	Speed at Contact mph	Maximum Longitudinal Acceleration g	Mod
															Softwood Trees, United States (Contin			
M113	NASA-A	144	Nov 1964	175	Pine	15	35	15	7.8	†	**	**	9,600	3,900	38	11.2	0.90	Shear Tensi
M113	NASA-B	19	Nov 1964	78	Pine	11	26	13	7.9	23,440	**	**	10,050	4,600	20	0.0	**	Elast
M113	NASA-D	29	Nov 1964	16	Pine	15	42	25	7.9	47,920	**	**	19,100	7,300	20	0.0	0.15	Tensi
M113	NASA-E	149	Nov 1964	180	Pine	30	45	12	7.9	25,760	**	**	13,800	2,000	20	0.0	**	Shear Tensi
M113	NASA-A	50	Nov 1964	41	Pine	30	49	20	7.9	†	**	**	10,500	2,500	38	0.0	**	Shear Tensi
M113	NASA-A	43	Nov 1964	89	Pine	25	52	20	7.9	†	**	**	20,300	3,750	38	5.2	0.40	Shear Tensio
M113	NASA-E	98	Nov 1964	129	Pine	20	48	20	7.9	†	**	**	18,900	4,600	38	11.6	††	Shear Tensio
M113	NASA-E	101	Nov 1964	132	Pine	35	58	25	7.9	†	**	**	19,100	5,400	38	8.1	††	Shear Tensio
M113	NASA-A	114	Nov 1964	[illegible]	Pine	18	45	18	7.9	†	**	**	13,400	4,000	38	8.0	1.00	Tensio
M113	NASA-E	27	Nov 1964	2	Pine	15	42	20	8.0	33,280	**	**	14,300	4,050	20	0.0	**	Tensio
M113	NASA-A	51	Nov 1964	56	Pine	10	46	25	8.1	†	**	**	10,300	1,450	38	0.0	**	Shear Tensio
M113	NASA-C	59	Nov 1964	30	Pine	15	39	20	8.1	††	**	**	††	††	38	††	†	Shear Tensio
M113	NASA-A	45	Nov 1964	91	Pine	30	54	30	8.2	†	**	**	11,400	3,100	38	0.0	**	Shear Tensio
M113	NASA-E	24	Nov 1964	81	Pine	30	51	23	8.3	54,560	**	**	15,000	5,350	20	0.0	**	Shear Tensio
M113	NASA-A	39	Nov 1964	85	Pine	45	70	10	8.3	**	**	**	**	**	20	0.0	**	No Fai
M113	NASA-E	153	Nov 1964	184	Pine	25	54	16	8.3	36,400	**	**	17,600	1,500	20	0.0	**	Shear (Tensio
M113	NASA-A	6	Nov 1964	60	Pine	15	47	24	8.3	†	**	**	8,150	1,400	56	0.0	**	Shear (Tensio
M113	NASA-A	52	Nov 1964	58	Pine	15	46	25	8.3	†	**	**	10,200	2,150	38	0.0	**	Shear (Tensio
M113	NASA-A	5	Nov 1964	61	Pine	12	48	24	8.4	†	**	**	8,400	2,600	56	0.0	**	Shear (Tensio
M113	NASA-A	138	Nov 1964	169	Pine	30	60	15	8.5	†	**	**	20,800	3,700	38	10.2	1.20	Shear (Tensio
M113	NASA-A	40	Nov 1964	86	Pine	45	56	20	8.6	57,680	**	**	18,000	6,350	20	0.0	**	Tension
M113	NASA-E	151	Nov 1964	182	Pine	10	51	24	8.8	46,480	**	**	16,800	3,200	20	0.0	**	Tension
M113	NASA-E	152	Nov 1964	183	Pine	18	42	18	8.8	†	**	**	17,400	--	20	0.0	**	Tension
M113	NASA-D	34	Nov 1964	24	Pine	30	45	30	9.0	43,920	**	**	17,000	3,850	20	0.0	**	No Fail
M113	NASA-E	154	Nov 1964	185	Pine	30	36	20	9.0	33,040	**	**	12,200	2,000	20	0.0	**	Tension
M113	NASA-E	155	Nov 1964	186	Pine	30	50	20	9.1	**	**	**	**	**	20	0.0	**	Tension
M113	NASA-A	41	Nov 1964	87	Pine	30	--	25	9.6	**	**	**	**	**	20	0.0	**	No Fail
M113	NASA-A	54	Nov 1964	93	Pine	40	--	30	9.6	†	**	**	--	2,050	20	0.0	**	No Fail
M113	NASA-B	12	Nov 1964	73	Pine	20	50	20	9.8	†	**	**	9,600	1,100	38	0.0	**	No Fail
M113	NASA-O	33	Nov 1964	20	Pine	15	--	35	10.0	**	**	**	**	**	56	0.0	**	Shear (Tension
M113	NASA-O	33A	Nov 1964	20	Pine	15	--	35	10.0	**	**	**	**	**	20	0.0	**	No Fail
M113	NASA-B	15	Nov 1964	76	Pine	18	63	30	11.0	†	**	**	12,600	3,500	20	0.0	**	No Fail
M113	NASA-B	14	Nov 1964	35	Pine	35	63	25	12.1	†	**	**	20,000	††	56	0.0	**	Shear (Tension
																		No Fail
															Hardwood Trees, United States			
M113	E-13	361	May 1964	18	Oak	4	9	3	1.1	132	333	††	96	88	20	2.4	0.0	Elastic
M37	NASA-F	32	Aug 1964	48	Oak	3	11	**	1.3	82	**	**	50	**	26	0.0	**	Elastic
M37	NASA-F	30	Aug 1964	46	Oak	**	13	**	1.5	152	**	**	60	**	26	0.0	**	Elastic
M113	E-13	366	May 1964	23	Oak	-5	9	-3	1.5	465	815	2,632	270	177	20	1.8	0.01	Elastic
M37	NASA-F	31	Aug 1964	47	Oak	3	12	**	1.7	452	**	**	200	**	26	0.0	**	Elastic
M37	E-7	419	May 1964	55	Hawthorn	1	7	3	2.0	346	1,139	1,542	160	**	26	1.8	**	Elastic
M37	NASA-F	34	Aug 1964	51	Oak	1	15	**	2.3	686	**	**	340	**	26	0.0	**	Elastic
M37	NASA-F	42	Aug 1964	59	Oak	**	15	**	2.5	1,500	**	**	724	**	26	0.0	**	Tension
M37	NASA-F	33	Aug 1964	49	Oak	4	**	**	2.7	2,936	**	**	780	**	26	0.0	**	Compress
M113	E-13	355	May 1964	12	Oak	5	15	10	2.8	2,782	5,659	2,990	1,454	541	20	1.7	-0.04	Elastic
M37	E-7	417	May 1964	53	Hawthorn	4	15	4	2.8	1,930	4,866	2,082	661	**	26	1.35	††	Elastic
M113	E-13	356	May 1964	13	Oak	2	12	10	2.9	2,145	5,344	5,465	1,493	566	20	1.6	-0.07	Elastic
M37	E-7	420	May 1964	56	Hawthorn	5	17	10	3.5	[illegible],880	2,096	2,348	895	**	26	1.6	-0.04	Elastic

(Continued)

** No measurement made.
† Total work not recorded.
†† Instrumentation failed.

A

Table B1 (Continued)

peed at tact mph	Maximum Longitudinal Acceleration g	Mode of Failure	Average Cone Index: 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	18- to 24-in. Layer	24- to 30-in. Layer	USCS Soil Classification: 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	Moisture Content, %: 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	Remarks
ees, United States (Continued)														
.2	0.90	Shear (soil) Tension (root)	317	518	507	**	**	ML	CL-ML	CL	17.8	17.3	18.8	Taproot failed 6 in. below ground surface
.0	**	Elastic (stem)	312	702	750	**	**	SC-SM	ML	CL	12.1	7.0	13.8	Undercarriage of vehicle scraped bark and wood from lower stem
.0	0.15	Tension (stem)	445	693	750	**	**	ML	CL	CL	12.8	8.0	9.1	Undercarriage of vehicle scraped bark and wood from lower stem
.0	**	Shear (soil) Tension (root)	315	550	540	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 24 in. below ground surface
.0	**	Shear (soil) Tension (root)	276	346	519	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 36 in. below ground surface
.2	0.40	Shear (soil) Tension (root)	385	395	378	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 24 in. below ground surface
6	††	Shear (soil) Tension (root)	183	287	426	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 24 in. below ground surface
1	††	Shear (soil) Tension (root)	101	140	256	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 36 in. below ground surface. Main stem failed about 38 ft above ground surface
0	1.00	Tension (root)	521	750	750	**	**	ML	CL-ML	CL	17.8	17.3	18.8	
0	**	Tension (root)	253	347	226	**	**	ML	ML	CL	13.5	11.4	14.1	Undercarriage of vehicle dragged on exposed root bulb
0	**	Shear (soil) Tension (root)	291	350	391	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 30 in. below ground surface
	†	Shear (soil) Tension (root)	253	379	387	**	**	CL-ML	CL-ML	CL	20.2	16.2	17.5	Taproot failed 36 in. below ground surface
	**	Shear (soil) Tension (root)	178	253	375	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 54 in. below ground surface
	**	Shear (soil) Tension (root)	210	284	378	**	**	ML	ML	CL	13.2	10.9	12.3	Taproot failed 30 in. below ground surface
	**	No Failure	329	387	397	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Vehicle immobilized
	**	Shear (soil) Tension (root)	178	292	378	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 30 in. below ground surface
	**	Shear (soil) Tension (root)	186	250	341	**	**	ML	CL-ML	CL	18.0	15.7	14.6	Taproot failed 36 in. below ground surface
	**	Shear (soil) Tension (root)	391	500	393	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Taproot failed 36 in. below ground surface
	**	Shear (soil) Tension (root)	166	158	445	**	**	ML	CL-ML	CL	16.7	14.5	14.0	Taproot failed 10 in. below ground surface. Undercarriage of vehicle dragged on exposed root bulb
	1.20	Shear (soil) Tension (root)	270	415	375	**	**	ML	CL-ML	CL	17.8	17.3	18.7	
	**	Tension (stem)	286	431	391	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Vehicle immobilized
	**	Tension (root)	246	335	388	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 24 in. below ground surface.
	**	No Failure	206	277	228	**	**	ML	ML	CL	15.0	12.1	13.5	Vehicle immobilized
	**	Tension (root)	199	239	328	**	**	ML	CL	CL	11.5	12.4	15.9	Taproot failed 42 in. below ground surface
	**	Tension (root)	261	337	326	**	**	ML	ML	CL	15.0	12.1	13.5	Taproot failed 18 in. below ground surface
	**	No Failure	213	299	356	**	**	ML	ML	CL	15.0	12.1	13.5	Vehicle immobilized
	**	No Failure	256	456	512	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Vehicle immobilized
	**	No Failure	318	483	272	**	**	ML	CL-ML	CL	17.8	17.3	18.7	Vehicle immobilized
	**	Shear (soil) Tension (root)	233	338	336	**	**	SC-SM	ML	CL	6.3	7.6	11.1	Undercarriage of vehicle scraped bark and wood from lower stem
	**	No Failure	332	448	465	**	**	ML	CL	CL	18.6	15.3	14.8	Vehicle immobilized
	**	No Failure	332	448	465	**	**	ML	CL	CL	18.6	15.3	14.8	Vehicle immobilized
	**	Shear (soil) Tension (root)	318	400	401	**	**	SM-SC	ML	CL	7.5	8.7	11.1	
	**	No Failure	177	218	273	**	**	SM-SC	ML	CL	8.5	6.9	6.9	Vehicle immobilized
rees, United States														
	0.0	Elastic (stem)	44	60	63	80	87	SP-SM	SP-SM	SP-SM	7.3	8.2	6.9	
	**	Elastic (stem)	200	240	240	290	380	CL-ML	CL-ML	**	17.6	13.1	13.0	
	**	Elastic (stem)	190	220	210	300	500	CL-ML	CL-ML	**	19.9	14.7	14.3	
	0.01	Elastic (stem)	55	69	76	81	92	SP-SM	SP-SM	SP-SM	7.4	7.8	7.2	
	**	Elastic (stem)	290	480	490	540	620	CL-ML	CL-ML	**	15.5	13.8	14.1	
	††	Elastic (stem)	102	105	90	111	120	SM	SP-SM	SP-SM	3.8	4.4	4.8	
	**	Elastic (stem)	170	220	210	280	370	CL-ML	CL-ML	**	12.4	14.8	16.3	
	**	Tension (stem)	210	310	260	290	420	CL-ML	CL-ML	**	11.0	10.0	12.5	
	**	Compression (stem)	250	320	330	400	590	CL-ML	CL-ML	**	15.3	13.6	14.5	
	-0.04	Elastic (stem)	56	92	92	83	92	SP-SM	SP-SM	SP-SM	8.7	8.1	7.9	
	††	Elastic (stem)	84	85	82	96	111	SM	SP-SM	SP-SM	3.8	4.4	4.8	
	-0.07	Elastic (stem)	50	65	67	82	95	SP-SM	SP-SM	SP-SM	8.7	8.1	7.9	
	-0.04	Elastic (stem)	86	150	157	139	126	SM	SP-SM	SM	3.8	4.4	4.8	

tinued)

B

Test Vehicle	Site No.	Test No.	Test Date	Tree No.	Tree Type (Common Name)	Branching Height ft	Tree Height ft	Crown Diameter ft	Stem Diameter 42 in. Aboveground, in.	Work Required to Fail Tree, lb-ft	Work Required to Override Tree, lb-ft	Maximum Tractive Force, lb	Maximum Horizontal Pushbar Force, lb	Maximum Vertical Pushbar Force, lb	Pushbar Height Aboveground in.	Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode of Fa
															Hardwood Trees, United States (Continued)			
M37	NASA-F	38	Aug 1964	55	Oak	7	25	**	3.7	3,724	**	**	1,580	**	26	0.0	**	Shear (soil) Tension (roo
M113	E-12	343	May 1964	1	Oak	4	18	4	3.8	5,714	8,872	3,601	4,247	639	20	2.6	-0.11	Tension (roo
M113	E-13	387	May 1964	44	Oak	7	21	12	3.8	5,128	13,498	6,031	1,953	613	32	1.5	-0.10	Shear (soil) Tension (roo
M37	NASA-F	41	Aug 1964	58	Oak	7	**	**	3.9	4,876	**	**	2,570	**	26	0.0	**	Tension (ste
M113	E-13	357	May 1964	14	Oak	6	20	12	3.9	6,523	6,898	4,476	3,264	1,155	20	1.9	-0.14	Shear (soil) Tension (roo
M37	NASA-F	44	Aug 1964	61	Oak	**	16	**	4.0	7,192	**	**	2,775	**	26	0.0	**	Tension (ste
M113	E-13	367	May 1964	24	Oak	6	24	12	4.1	2,902	4,632	3,765	3,382	484	20	1.5	-0.10	Shear (soil) Tension (roo
M113	E-13	383	May 1964	40	Oak	7	20	12	4.1	9,414	11,306	8,650	4,217	1,172	20	8.9	-2.06	Shear (soil) Tension (roo
M113	E-13	359	May 1964	16	Oak	9	15	**	4.2	7,121	15,610	4,426	††	1,327	20	2.1	-0.20	Compression (
M37	E-7	421	May 1964	57	Hawthorn	4	20	15	4.3	1,712	1,865	2,101	986	**	26	1.7	††	Tension (roo
M113	E-13	372	May 1964	29	Oak	9	20	12	4.4	††	4,881	4,363	††	679	20	2.4	-0.19	Shear (soil) Tension (roo
M113	E-13	371	May 1964	28	Oak	7	20	12	4.5	3,792	4,386	2,833	3,792	431	20	2.2	-0.19	Shear (soil) Tension (roo
M37	NASA-F	35	Aug 1964	50	Oak	6	**	**	4.8	8,903	**	**	3,710	**	26	0.0	**	Shear (soil) Tension (roo
M113	E-12	345	May 1964	3	Oak	3	21	5	4.8	††	20,329	7,014	††	2,913	20	2.9	-0.50	Tension (ste
M113	E-13	364	May 1964	21	Oak	6	18	10	4.9	4,693	7,559	4,778	4,355	620	20	1.7	-0.14	Shear (soil) Tension (roo
M113	E-13	384	May 1964	41	Oak	6	20	12	4.9	††	††	††	††	††	20	††	††	Tension (ste
M113	E-13	388	May 1964	45	Oak	6	18	12	4.9	5,287	14,304	4,048	3,425	1,513	32	2.0	-0.14	Shear (soil) Tension (roo
M37	NASA-F	40	Aug 1964	57	Oak	7	27	**	5.0	7,934	**	**	2,900	**	26	0.0	**	Shear (soil) Tension (roo
M37	E-12	344	May 1964	2	Oak	6	21	5	5.0	9,240	14,735	6,082	3,960	1,379	20	2.5	-0.08	Tension (roo
M113	B	11	Nov 1964	49	Oak	**	40	**	5.[illegible]	†	**	**	3,400	730	56	0.0	**	Tension (ste
M113	E-13	376	May 1964	33	Oak	6	24	6	5.1	4,804	5,[illegible]5	4,615	3,665	613	20	1.9	-0.06	Shear (soil) Tension (roo
M113	E-13	389	May 1964	46	Oak	7	20	6	5.1	7,76[illegible]	10,508	5,496	2,623	623	32	1.[illegible]	-0.07	Shear (soil) Tension (roo
M37	NASA-F	39	Aug 1964	56	Oak	7	26	**	5.2	6,161	**	**	3,700	**	26	0.0	**	Shear (soil) Tension (roo
M37	NASA-F	43	Aug 1964	60	Oak	**	20	**	5.3	13,173	**	**	4,200	**	26	0.0	**	Shear (soil) Tension (roo
M37	E-13	377	May 1964	34	Oak	5	27	12	5.3	14,266	18,879	4,489	5,528	1,558	20	2.2	-0.18	Shear (soil) Tension (roo
M113	E-13	381	May 1964	38	Oak	8	20	12	5.3	21,831	23,055	6,308	8,014	3,186	20	10.3	-0.41	Shear (soil) Tension (roo
M113	E-13	386	May 1964	43	Oak	6	27	12	5.6	13,984	14,410	5,106	3,592	1,294	32	1.7	-0.60	Shear (soil) Tension (roo
M113	E-13	363	May 1964	20	Oak	5	24	12	5.7	10,804	11,174	9,167	4,990	2,058	20	1.2	-0.20	Shear (soil) Tension (roo
M113	E-13	379	May 1964	36	Oak	7	22	12	6.1	33,636	42,809	6,226	10,594	3,599	20	10.4	-2.28	Shear (soil) Tension (roo
M113	E-13	362	May 1964	19	Oak	7	21	18	6.2	††	††	††	††	††	20	††	††	Shear (soil) Tension (roo
M113	E-12	346	May 1964	4	Oak	45	24	15	6.3	37,512	58,010	11,086	--	2,198	20	3.[illegible]	-0.40	Tension (roo
M113	E-13	375	May 1964	32	Oak	11	30	12	6.3	8,100	8,401	5,981	7,436	1,139	20	2.2	††	Shear (soil) Tension (roo
M113	E-13	392	May 1964	49	Oak	12	25	12	6.3	7,178	7,907	7,221	4,526	764	32	1.3	-0.18	Shear (soil) Tension (roo
M113	E-13	374	May 1964	31	Oak	6	39	12	6.5	31,309	4[illegible],093	12,025	--	1,952	20	2.2	††	Shear (soil) Tension (roo
M113	E-13	380	May 1964	37	Oak	3	25	12	6.5	24,393	30,674	7,725	13,728	2,9[illegible]	[illegible]	11.4	-1.91	Shear (soil) Tension (roo
M113	E-12	348	May 1964	6	Oak	6	27	6	6.6	19,752	23,573	7,215	8,407	1,974	20	2.1	-0.30	Shear (soil) Tension (roo
M113	NASA-B	7	Nov 1964	52	Oak	16	40	18	6.7	†	**	**	7,900	1,700	56	0.0	**	Tension (ste
M113	NASA-A	1	Nov 1964	53	Oak	8	36	18	6.8	†	**	**	5,750	1,200	56	0.0	**	Shear (soil) Tension (roo
M113	E-12	347	May 1964	5	Oak	6	27	18	6.9	10,923	13,219	6,535	[illegible],294	2,805	20	[illegible]	-0.30	Shear (soil) Tension (roo
M113	E-13	365	May 1964	22	Oak	7	22	18	7.2	10,560	**	8,871	10,400	1,935	[illegible]	[illegible].0	-0.33	Shear (soil) Tension (roo

(Continued)

** No measurement made.
† Total work not recorded.
†† Instrumentation failed

A

Table B1 (Continued)

Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode of Failure	Average Cone Index 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	18- to 24-in. Layer	24- to 30-in. Layer	USCS Soil Classification 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	Moisture Content, % 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	Remarks
Trees, United States (Continued)														
0.0	**	Shear (soil) Tension (root)	150	160	130	190	320	CL-ML	CL-ML	**	19.0	17.5	17.6	
2.6	-0.11	Tension (root)	43	61	71	83	95	SP-SM	SP-SM	SP-SM	7.5	7.6	6.7	
1.5	-0.10	Shear (soil) Tension (root)	61	66	71	[illegible]	78	SP-SM	SP-SM	SP-SM	8.1	6.9	7.1	Tree fell off to side and vehicle did not override the entire crown
0.0	**	Tension (stem)	80	120	160	230	310	CL-ML	CL-ML	**	13.9	12.5	13.8	
1.9	-0.14	Shear (soil) Tension (root)	52	70	67	73	86	SP-SM	SP-SM	SP-SM	8.7	8.1	7.9	Stem fell against a neighboring tree before contacting the ground
0.0	**	Tension (stem)	160	220	270	330	440	CL-ML	CL-ML	**	12.0	10.0	9.4	
1.5	-0.10	Shear (soil) Tension (root)	55	70	67	68	85	SP-SM	SP-SM	SP-SM	7.4	7.8	7.2	
8.9	-2.06	Shear (soil) Tension (root)	50	70	64	72	92	SP-SM	SP-SM	SP-SM	5.1	5.8	5.2	
2.1	-0.20	Compression (stem)	60	74	69	75	90	SP-SM	SP-SM	SP-SM	8.5	8.0	7.4	
1.7	††	Tension (root)	87	130	102	98	100	SM	SP-SM	SP-SM	3.8	4.4	4.8	
2.4	-0.19	Shear (soil) Tension (root)	57	67	79	85	92	SP-SM	SF-SM	SP-SM	9.6	7.1	7.1	
2.2	-0.19	Shear (soil) Tension (root)	59	78	78	83	92	SP-SM	SP-SM	SP-SM	9.6	7.1	7.1	
0.0	**	Shear (soil) Tension (root)	310	550	540	540	610	CL-ML	CL-ML	**	12.8	12.1	13.6	
2.9	-0.50	Tension (stem)	43	68	76	74	81	SP-SM	SP-SM	SP-SM	7.5	7.6	6.7	
1.7	-0.14	Shear (soil) Tension (root)	55	74	76	77	88	SP-SM	SP-SM	SP-SM	7.4	7.8	7.2	Tree fell off to side and vehicle did not override the entire crown
††	††	Tension (stem)	63	70	63	73	90	SP-SM	SP-SM	SP-SM	5.1	5.8	5.2	Stem failed at pushbar height and fell forward into another tree
2.0	-0.14	Shear (soil) Tension (root)	53	78	78	56	102	SP-SM	SP-SM	SP-SM	8.2	6.9	7.1	Tree was entirely uprooted and dragged beneath vehicle for a distance of 9.0 ft
0.0	**	Shear (soil) Tension (root)	130	150	210	260	340	CL-ML	CL-ML	**	17.3	12.9	14.7	
2.5	-0.08	Tension (root)	45	67	65	65	76	SP-SM	SP-SM	SP-SM	7.5	7.6	6.7	
0.0	**	Tension (stem)	91	290	314	**	**	SC-SM	ML	CL	5.4	6.8	6.8	Stem failed in tension [illegible] ft above ground surface
1.9	-0.06	Shear (soil) Tension (root)	41	80	88	99	124	SP-SM	SP-SM	SP-SM	8.6	7.7	7.5	
1.8	-0.07	Shear (soil) Tension (root)	44	64	74	84	100	SP-SM	SP-SM	SP-SM	6.1	6.9	7.1	
0.0	**	Shear (soil) Tension (root)	200	220	210	200	190	CL-ML	CL-ML	**	17.0	19.2	[illegible]	
0.0	**	Shear (soil) Tension (root)	190	210	200	260	450	CL-ML	CL-ML	**	21.2	15.3	16.5	
.2	-0.18	Shear (soil) Tension (root)	51	71	67	69	80	SP-SM	SP-SM	SP-SM	8.6	7.7	7.5	
.3	-0.41	Shear (soil) Tension (root)	59	80	78	88	96	SP-SM	SP-SM	SP-SM	6.8	5.9	5.9	
.7	-0.60	Shear (soil) Tension (root)	53	65	75	96	126	SP-SM	SP-SM	SP-SM	7.1	6.9	7.1	Stem appeared infected at base
2	-0.20	Shear (soil) Tension (root)	48	66	71	86	94	SP-SM	SP-SM	SP-SM	7.4	7.8	7.2	
4	-2.28	Shear (soil) Tension (root)	60	71	73	73	87	SP-SM	SP-SM	SP-SM	6.5	5.9	5.9	
	††	Shear (soil) Tension (root)	51	67	75	80	94	SP-SM	SP-SM	SP-SM	7.[illegible]	8.2	6.9	Tree fell off to side and vehicle did not override the entire crown
2	-0.40	Tension (root)	50	70	74	91	95	SP-SM	SP-SM	SP-SM	6.0	7.5	5.1	
2	††	Shear (soil) Tension (root)	54	75	78	90	92	SP-SM	SP-SM	SP-SM	5.6	7.7	7.5	
3	-0.18	Shear (soil) Tension (root)	70	97	95	108	118	SP-SM	SP-SM	SP-SM	6.1	6.5	6.1	
2	††	Shear (soil) Tension (root)	58	79	76	80	89	SP-SM	SP-SM	SP-SM	[illegible]	7.7	7.5	
	-1.91	Shear (soil) Tension (root)	65	79	74	73	96	SP-SM	SP-SM	SP-SM	[illegible]	5.9	5.4	Tree failed 4 ft above ground surface and fell on top of vehicle
	-0.30	Shear (soil) Tension (root)	61	93	95	98	106	SP-SM	SP-SM	SP-SM	[illegible]	[illegible]	5.1	Tree appeared to be infected
	**	Tension (stem)	216	275	271	**	**	SC-SM	ML	CL	[illegible]	[illegible]	7.5	
	**	Shear (soil) Tension (root)	160	211	407	**	**	ML	CL-ML	CL	[illegible]	16.0	15.1	
	-0.30	Shear (soil) Tension (root)	43	65	70	84	108	SP-SM	SP-SM	SP-SM	6.0	[illegible]	[illegible]	
	-0.33	Shear (soil) Tension (root)	60	70	58	75	95	SP-SM	SP-SM	SP-SM	[illegible]	[illegible]	6.9	Tree was entirely uprooted and dragged beneath vehicle for a distance of [illegible] ft

(Continued)

B

Table B1 (Continued)

Test Vehicle	Site No.	Test No.	Test Date	Tree No.	Tree Type (Common Name)	Branching Height ft	Tree Height ft	Crown Diameter ft	Stem Diameter 4½ in. Aboveground, in.	Work Required to Fail Tree, lb-ft	Work Required to Override Tree, lb-ft	Maximum Tractive Force, lb	Maximum Horizontal Pushbar Force, lb	Maximum Vertical Pushbar Force, lb	Pushbar Height Aboveground in.	Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode o
															Hardwood Trees, United States (Continued)			
M113	E-13	390	May 1964	47	Oak	6	25	18	7.3	16,159	34,231	9,891	8,407	1,615	32	1.8	-2.40	Shear (Tension
M113	E-12	349	May 1964	7	Oak	5	27	20	7.5	32,910	33,268	11,446	11,977	3,195	20	[illegible]	-0.39	Shear (Tension
M113	E-13	358	May 1964	15	Oak	6	24	20	7.6	55,487	81,198	14,556	12,078	3,566	20	1.5	-0.34	Shear (Tension
M113	E-13	378	May 1964	35	Oak	7	35	15	7.8	48,238	50,888	8,090	21,672	6,513	20	11.4	-2.20	Tension
M113	E-13	393	May 1964	50	Oak	6	21	24	7.8	17,119	62,725	11,546	7,695	1,380	32	1.1	-0.23	Shear (Tension
M113	E-13	368	May 1964	25	Oak	6	24	20	8.[illegible]	17,090	19,768	9,910	7,300	2,008	20	0.9	-0.20	Shear (Tension
M113	E-13	391	May 1964	48	Oak	6	30	24	3.3	28,125	48,866	9,758	8,320	1,318	32	[illegible].9	-1.08	Shear (Tension
M113	NASA-A	2	Nov 1964	54	Oak	12	44	23	8.5	†	**	**	8,900	2,550	56	0.0	**	Shear (Tension
M113	E-12	350	May 1964	8	Oak	8	24	12	8.6	21,029	22,83[illegible]	11,37[illegible]	10,971	2,399	20	1.4	-0.39	Shear (Tension
M113	E-13	385	May 1964	42	Oak	7	27	24	8.6	36,679	105,539	11,528	12,515	2,552	32	2.1	-2.54	Shear (Tension
M113	E-13	382	May 1964	39	Oak	7	25	18	9.0	45,656	65,514	11,490	23,846	5,805	20	8.9	-2.00	Tension
M113	E-13	360	May 1964	17	Oak	6	--	18	9.3	35,[illegible]	50,982	11,484	13,159	2,477	20	2.3	-0.54	Shear (Tension
M113	E-13	369	May 1964	26	Oak	6	27	24	9.4	43,539	82,948	15,072	14,080	3,800	20	1.7	-0.47	Shear (Tension
M113	E-13	394	May 1964	51	Oak	10	30	24	10.2	††	††	††	††	††	32	††	††	Shear (Tension
M113	E-12	354	May 1964	11	Oak	5	27	14	10.8	35,119	45,755	16,866	15,020	2,396	20	1.3	-0.60	Shear (Tension
M113	E-13	370	May 1964	27	Oak	10	33	18	11.4	55,903	88,452	16,438	20.617	2,884	20	2.2	-0.70	Shear (Tension
M113	E-12	352	May 1964	10	Oak	9	33	20	11.8	††	††	17,018	††	††	20	††	††	
M113	E-12	353	May 1964	10	Oak	9	33	20	11.8	84,066	107,882	13,303	35,400	4,944	20	5.0	-0.29	Shear (Tension
M113	E-13	395	M[illegible] 1964	52	Oak	4	30	18	12.9	††	††	16,885	††	16,652	32	2.0	††	
M113	E-13	396	[illegible] 964	52	Oak	4	30	18	12.9	††	103,364	17,112	††	††	32	9.0	[illegible].309	Shear (Tension
															Hardwood Trees, Thailand			
M113	5V-S-1	53	Sept 1965	37	Hieng	7	9	4	1.8	221	††	††	188	53	20	1.7	0.0	Elastic
M113	5V-S-1	1	Sept 1965	1	Hieng	6	9	2	2.0	299	††	††	116	72	32	2.2	††	Tension
M113	5V-S-1	8	Sept 1965	6	Hieng	5	12	4	2.0	310	††	††	130	41	32	1.7	††	Compress
M113	5V-S-1	7	Sept 1965	5	Hieng	10	12	5	2.2	408	††	††	164	49	32	1.4	0.03	Elastic
M113	5V-S-1	2	Sept 1965	2	Hieng	6	15	2	2.3	††	††	††	170	65	32	1.6	††	Tension
M113	5V-S-1	23	Sept 1965	16	Hieng	12	15	5	2.3	795	††	1,603	408	††	32	2.1	††	Compress
M113	5V-S-1	30	Sept 1965	26	Hieng	10	18	4	2.7	1,670	1,889	2,836	718	146	32	1.9	0.02	
M113	5V-S-1	62	Sept 1965	60	Hieng	7	15	6	2.7	2,[illegible]50	††	††	75[illegible]	310	20	2.0	††	Elastic
M113	5V-S-1	3	Sept 1965	3	Hieng	13	17	6	2.9	1,239	6,195	5,053	516	220	32	1.6	††	Tension
M113	5V-S-1	26	Sept 1965	11	Hieng	6	20	[illegible]	2.9	1,458	††	††	999	302	32	2.1	††	Shear (Tension
M113	5V-S-1	6	Sept 1965	9	Hieng	8	21	6	3.1	1,797	††	††	653	362	32	1.8	††	Shear (Tension
M113	5V-S-1	29	Sept 1965	27	Hieng	7	15	5	3.3	2,713	††	3,858	1,305	418	32	1.7	0.03	Shear (Tension
M113	5V-S-1	10	Sept 1965	24	Hieng	7	18	12	3.5	2,330	††	3,306	1,170	413	32	1.6	0.04	Shear (Tension
M113	5V-S-1	3[illegible]	Sept 1965	35	Hieng	4	15	4	3.9	3,295	7,779	2,785	1,147	318	3[illegible]	[illegible]	0.04	Shear (Tension
M113	5V-S-1	59	Sept 1965	57	Hieng	10	18	6	3.9	3,073	9,952	2,858	1,[illegible]60	583	20	2.1	0.07	Shear (Tension
M113	5V-S-1	5	Sept 1965	8	Hieng	12	[illegible]5	9	4.0	2,772	5,634	2,391	94[illegible]	360	3[illegible]	2.0	0.08	Shear (Tension
M113	5V-S-1	16	Sept 1965	12	Hieng	5	21	8	4.0	3,400	7,354	3,955	1,405	††	32	2.1	0.10	Shear (Tension
M113	5V-S-1	27	Sept 1965	25	Hieng	7	21	15	4.0	3,763	5,350	3,308	1,845	1,510	3[illegible]	2.[illegible]	0.12	Shear (Tension
M113	5V-S-1	32	Sept 1965	34	Hieng	7	21	6	4.0	5,472	††	††	1,613	600	32	2.1	0.[illegible]	Shear (Tension
M113	5V-S-1	56	Sept 1965	55	Hieng	7	21	7	4.3	4,940	5,500	2,664	2,282	717	20	[illegible]	0.13	Shear (Tension

(Continued)

** No measurement made.
† Total work not recorded.
†† Instrumentation failed.

A

Table B1 (Continued)

Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode of Failure	Average Cone Index 0- to 6-in. Layer	Average Cone Index 6- to 12-in. Layer	Average Cone Index 12- to 18-in. Layer	Average Cone Index 18- to 24-in. Layer	Average Cone Index 24- to 30-in. Layer	USCS Soil Classification 0- to 6-in. Layer	USCS Soil Classification 6- to 12-in. Layer	USCS Soil Classification 12- to 18-in. Layer	Moisture Content, % 0- to 6-in. Layer	Moisture Content, % 6- to 12-in. Layer	Moisture Content, % 12- to 18-in. Layer	Remarks
od Trees, United States (Continued)														
1.8	-2.40	Shear (soil) Tension (root)	61	83	76	96	115	SP-SM	SP-SM	SP-SM	6.1	6.5	6.1	
2.3	-0.39	Shear (soil) Tension (root)	64	83	89	102	100	SP-SM	SP-SM	SP-SM	6.8	5.8	5.2	
1.5	-0.34	Shear (soil) Tension (root)	50	63	66	83	95	SP-SM	SP-SM	SP-SM	8.5	6.0	7.4	
11.4	-2.20	Tension (stem)	47	65	72	78	89	SP-SM	SP-SM	SP-SM	8.6	7.7	7.5	Tree failed at pushbar height and fell on top of vehicle
1.1	-0.23	Shear (soil) Tension (root)	59	81	87	95	106	SP-SM	SP-SM	SP-SM	8.1	6.5	6.1	
0.9	-0.20	Shear (soil) Tension (root)	57	71	75	92	107	SP-SM	SP-SM	SP-SM	7.3	8.2	6.9	
1.9	-1.08	Shear (soil) Tension (root)	42	62	83	91	92	SP-SM	SP-SM	SP-SM	8.1	6.5	6.1	
0.0	••	Shear (soil) Tension (root)	145	162	178	••	••	ML	CL-ML	CL	12.0	16.0	20.0	
1.4	-0.39	Shear (soil) Tension (root)	47	64	67	83	104	SP-SM	SP-SM	SP-SM	6.8	5.8	5.2	
2.1	-2.54	Shear (soil) Tension (root)	67	90	97	96	112	SP-SM	SP-SM	SP-SM	5.1	5.8	[illegible]	
8.9	-2.00	Tension (stem)	58	75	79	91	105	SP-SM	SP-SM	SP-SM	6.8	5.9	5.9	Tree failed [illegible] in. above ground surface and fell forward into another tree
2.3	-0.54	Shear (soil) Tension (root)	48	67	73	83	103	SP-SM	SP-SM	SP-SM	8.5	[illegible]	7.4	
1.7	-0.47	Shear (soil) Tension (root)	52	81	96	99	104	SP-SM	SP-SM	SP-SM	9.6	7.1	7.1	
††	††	Shear (soil) Tension (root)	59	81	94	111	129	SP-SM	SP-SM	SP-SM	8.1	6.5	6.1	
1.3	-0.60	Shear (soil) Tension (root)	61	83	84	93	95	SP-SM	SP-SM	SP-SM	8.1	7.6	[illegible]	
2.2	-0.70	Shear (soil) Tension (root)	62	86	97	101	109	SP-SM	SP-SM	SP-SM	9.6	7.1	7.1	
††	††	••	64	83	89	102	100	SP-SM	SP-SM	SP-SM	6.8	5.8	5.2	Vehicle immobilized
5.0	-0.29	Shear (soil) Tension (root)	64	83	89	102	100	SP-SM	SP-SM	SP-SM	6.8	5.8	5.2	
2.0	††	••	63	107	155	175	185	SP-SM	SP-SM	SP-SM	5.1	5.8	5.2	Vehicle immobilized
9.0	-2.309	Shear (soil) Tension (root)	63	107	155	17[illegible]	185	SP-SM	SP-SM	SP-SM	5.1	5.8	5.[illegible]	Vehicle immobilized
ardwood Trees, Thailand														
1.7	0.0	Elastic (stem)	175	195	186	157	163	SM	CL-ML	••	16.4	17.2	15.4	
2.2	††	Tension (stem)	167	230	275	••	••	SM	CL-ML	••	••	••	••	Vehicle hull contacted stem before the pushbar had completed the stem failure
1.7	††	Compression (stem)	185	289	246	••	••	SM	CL-ML	••	15.8	15.[illegible]	14.8	
1.4	0.03	Elastic (stem)	201	200	197	••	••	SM	CL-ML	••	15.8	15.9	14.7	
1.6	††	Tension (stem)	148	238	242	••	••	SM	CL-ML	••	••	••	••	Vehicle hull contacted stem before the pusher had [illegible] the stem failure
2.1	††	Compression (stem)	136	196	169	136	174	SM	CL-ML	••	16.9	16.4	16.[illegible]	Stem appeared to be infected at base
1.9	0.02	••	••	••	••	••	••	SM	CL-ML	••	••	••	••	
2.0	††	Elastic (stem)	••	••	••	••	••	SM	CL-ML	••	••	••	••	
1.6	††	Tension (stem)	166	214	174	••	••	SM	CL-ML	••	••	••	••	
2.1	††	Shear (soil) Tension (root)	189	192	182	••	••	SM	CL-ML	••	16.7	15.5	15.9	Tree appeared to be infected
1.8	††	Shear (soil) Tension (root)	191	248	163	••	••	SM	CL-ML	••	16.7	15.5	15.9	
.7	0.03	Shear (soil) Tension (root)	166	196	211	216	201	SM	CL-ML	••	17.1	17.4	16.1	
.6	0.04	Shear (soil) Tension (root)	187	2	212	172	160	SM	CL-ML	••	15.[illegible]	17.1	15.[illegible]	
.2	0.04	Shear (soil) Tension (root)	163	[illegible]	152	225	327	SM	CL-ML	••	16.[illegible]	16.7	[illegible]	
.1	0.07	Shear (soil) Tension (root)	184	196	135	182	169	SM	CL-ML	••	16.6	16.2	15.4	
.0	0.18	Shear (soil) Tension (root)	186	268	194	••	••	SM	CL-ML	••	16.7	15.5	15.9	Entire crown was not overridden due to short departure lane
.1	0.10	Shear (soil) Tension (root)	142	201	208	••	••	SM	CL-ML	••	18.0	[illegible]	14.5	
1	0.12	Shear (soil) Tension (root)	184	228	180	170	117	SM	CL-ML	••	17.1	17.4	16.1	
1	0.08	Shear (soil) Tension (root)	196	232	191	143	132	SM	CL-ML	••	15.9	17.2	17.7	
4	0.13	Shear (soil) Tension (root)	179	248	275	283	204	SM	CL-ML	••	14.7	17.[illegible]	15.9	

(Continued)

B

Test Vehicle	Site No.	Test No.	Test Date	Tree No.	Tree Type (Common Name)	Branching Height ft	Tree Height ft	Crown Diameter ft	Stem Diameter 42 in. Aboveground, in.	Work Required to Fail Tree, lb-ft	Work Required to Override Tree, lb-ft	Maximum Tractive Force, lb	Maximum Horizontal Pushbar Force, lb	Maximum Vertical Pushbar Force, lb	Pushbar Height Aboveground in.	Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode o…
															Hardwood Trees, Thailand (Continued)			
M113	5V-8-1	22	Sept 1965	22	Hieng	12	24	8	4.5	2,930	4,671	3,768	2,363	†*	32	2.2	0.09	Shear (Tension
M113	5V-8-1	60	Sept 1965	58	Hieng	9	21	8	4.5	††	††	††	††	††	20	††	††	Shear (Tension
M113	5V-8-1	11	Sept 1965	14	Hieng	9	24	12	4.6	4,814	7,886	4,668	2,657	722	32	1.9	0.12	Shear (Tension
M113	5V-8-1	9	Sept 1965	10	Hieng	7	33	10	4.7	8,533	41,504	2,417	2,893	772	32	1.4	0.12	Shear (Tension
M113	5V-8-1	19	Sept 1965	32	Hieng	5	15	12	4.8	3,452	22,469	3,806	1,678	493	32	1.7	0.15	Shear (Tension
M113	5V-8-1	40	Sept 1965	43	Hieng	15	30	10	4.8	3,504	4,270	3,092	4,373	1,011	20	1.9	0.12	Compre…
M113	5V-8-1	55	Sept 1965	53	Hieng	9	25	12	4.8	4,230	5,792	3,535	2,821	1,980	20	1.7	0.24	Shear (Tension
M113	5V-8-1	20	Sept 1965	33	Hieng	8	27	8	4.9	7,283	††	3,021	992	††	32	2.1	0.08	
M113	5V-8-1	61	Sept 1965	59	Hieng	10	24	7	4.9	8,700	8,090	4,386	2,472	648	20	2.1	0.10	Shear (Tension
M113	5V-8-1	21	Sept 1965	23	Hieng	10	27	11	5.0	6,029	7,244	5,855	2,744	720	32	2.0	0.10	Shear (Tension
M113	5V-8-1	35	Sept 1965	36	Hieng	10	25	10	5.0	9,179	17,864	4,135	2,904	1,165	20	1.9	0.10	Shear (Tension
M113	5V-8-1	47	Sept 1965	47	Hieng	8	27	6	5.0	5,400	11,050	4,560	3,460	903	20	2.0	0.18	Shear (Tension
M113	5V-8-1	28	Sept 1965	28	Hieng	11	33	14	5.1	7,130	9,100	††	††	1,239	32	2.0	††	Shear (Tension
M113	5V-8-1	54	Sept 1965	52	Hieng	8	24	8	5.1	8,453	34,188	5,463	5,441	2,567	20	2.0	0.20	Shear (Tension
M113	5V-8-1	13	Sept 1965	19	Hieng	7	30	8	5.6	6,621	24,555	8,846	7,040	816	32	1.7	0.16	
M113	5V-8-1	39	Sept 1965	44	Hieng	15	30	8	5.8	11,220	18,154	4,606	4,034	988	20	2.0	0.14	Shear (Tension
M113	5V-8-1	57	Sept 1965	56	Hieng	10	30	9	5.8	6,906	13,425	4,350	4,682	938	20	2.1	0.21	Shear (Tension
M113	5V-8-1	58	Sept 1965	54	Hieng	12	30	13	6.0	14,723	18,494	10,957	6,590	1,080	20	1.6	0.22	Shear (Tension
M113	5V-8-1	17	Sept 1965	21	Hieng	10	27	5	6.1	5,440	7,952	5,153	3,956	589	32	2.0	0.16	Shear (Tension
M113	5V-8-1	46	Sept 1965	41	Hieng	10	25	5	6.1	6,736	8,964	2,815	4,030	672	20	1.7	0.06	Shear (Tension
M113	5V-8-1	12	Sept 1965	13	Hieng	9	33	14	6.4	14,435	20,166	5,365	5,120	1,130	32	1.7	0.16	Shear (Tension
M113	5V-8-1	15	Sept 1965	18	Hieng	10	33	8	6.4	8,600	9,701	4,061	4,785	667	32	1.8	0.19	Shear (Tension
M113	5V-8-1	42	Sept 1965	40	Hieng	7	28	5	6.4	9,563	22,375	6,420	3,612	1,350	20	2.0	0.19	Shear (Tension
M113	5V-8-1	37	Sept 1965	45	Hieng	7	30	8	6.7	10,175	15,957	6,423	6,929	1,870	20	1.9	0.27	Tension
M113	5V-8-1	36	Sept 1965	42	Hieng	9	30	12	7.2	12,892	17,649	7,258	6,512	925	20	1.8	0.31	Shear (Tension
M113	5V-8-1	4	Sept 1965	4	Hieng	8	34	24	7.3	12,686	18,017	9,749	9,263	1,015	32	2.2	0.32	Shear (Tension
M113	5V-8-1	18	Sept 1965	31	Hieng	7	30	10	7.4	15,018	50,385	6,045	5,497	2,040	32	2.5	0.24	Shear (Tension
M113	5V-8-1	38	Sept 1965	46	Hieng	9	32	8	7.4	14,413	34,197	7,164	10,533	1,845	20	2.3	0.47	Shear (Tension
M113	5V-8-1	48	Sept 1965	48	Hieng	4	25	14	7.5	14,932	16,513	7,959	7,121	1,481	20	1.8	0.31	
M113	5V-8-1	41	Sept 1965	38	Hieng	10	25	16	8.0	26,588	93,331	14,942	7,861	2,096	20	2.1	0.33	Shear (Tension
M113	5V-8-1	14	Sept 1965	20	Hieng	12	45	24	8.4	23,650	27,056	7,652	7,555	1,896	32	2.3	0.26	
M113	5V-8-1	49	Sept 1965	49	Hieng	6	26	15	8.8	25,304	††	††	11,634	1,836	20	1.9	0.42	Shear (Tension
M113	5V-8-1	43	Sept 1965	39	Hieng	15	35	16	9.1	††	††	†*	††	††	20	††	††	Shear (Tension
M113	5V-8-1	52	Sept 1965	61	Hieng	12	30	12	9.1	25,650	55,506	13,509	14,947	3,341	20	2.2	0.73	Shear (Tension
M113	5V-8-1	24	Sept 1965	15	Hieng	10	45	11	9.6	††	††	††	††	††	32	††	††	Compre…
M113	5V-8-1	33	Sept 1965	30	Hieng	8	40	14	9.7	26,854	38,522	12,171	14,523	1,298	32	2.2	0.59	Shear (Tension
M113	5V-8-1	50	Sept 1965	51	Hieng	15	35	20	10.0	50,582	101,238	21,644	17,248	4,150	20	1.7	0.62	Shear (Tension
M113	5V-8-1	51	Sept 1965	50	Hieng	20	45	10	10.7	42,329	101,796	18,368	21,961	4,425	20	3.4	0.99	Shear (Tension
M113	5V-8-1	34	Sept 1965	29	Hieng	11	45	15	13.0	46,640	150,544	16,539	17,466	4,296	20	1.5	0.72	Shear (Tension

** No measurement made.
†† Instrumentation failed.

A

Table B1 (Concluded)

Speed at Contact mph	Maximum Longitudinal Acceleration g	Mode of Failure	Average Cone Index 0- to 6-in. Layer	Average Cone Index 6- to 12-in. Layer	Average Cone Index 12- to 18-in. Layer	Average Cone Index 18- to 24-in. Layer	Average Cone Index 24- to 30-in. Layer	USCS Soil Classification 0- to 6-in. Layer	USCS Soil Classification 6- to 12-in. Layer	USCS Soil Classification 12- to 18-in. Layer	Moisture Content, % 0- to 6-in. Layer	Moisture Content, % 6- to 12-in. Layer	Moisture Content, % 12- to 18-in. Layer	Remarks
Trees, Thailand (Continued)														
2.2	0.09	Shear (soil) Tension (root)	159	213	200	155	186	SM	CL-ML	**	18.0	17.2	17.0	
††	††	Shear (soil) Tension (root)	**	**	**	**	**	SM	CL-ML	**	**	**	**	Entire crown was not overridden due to short departure lane
1.9	0.12	Shear (soil) Tension (root)	178	214	176	159	184	SM	CL-ML	**	16.2	16.7	16.4	
1.4	0.12	Shear (soil) Tension (root)	209	245	183	**	**	SM	CL-ML	**	16.5	17.1	16.0	
1.7	0.15	Shear (soil) Tension (root)	160	180	172	147	152	SM	CL-ML	**	17.0	17.8	16.8	Tree fell off to side and vehicle did not override the entire crown
1.9	0.12	Compression (stem)	159	153	172	184	192	SM	CL-ML	**	11.8	22.5	15.3	
1.7	0.24	Shear (soil) Tension (root)	179	248	275	283	294	SM	CL-ML	**	14.7	17.3	15.9	
2.1	0.08	**	176	206	160	111	140	SM	CL-ML	**	16.2	16.4	16.5	
2.1	0.10	Shear (soil) Tension (root)	**	**	**	**	**	SM	CL-ML	**	**	**	**	
2.0	0.10	Shear (soil) Tension (root)	191	202	164	179	195	SM	CL-ML	**	18.0	17.2	17.0	
1.9	0.10	Shear (soil) Tension (root)	168	166	155	137	150	SM	CL-ML	**	15.5	15.7	16.2	
2.0	0.18	Shear (soil) Tension (root)	133	159	150	185	262	SM	CL-ML	**	14.1	13.4	16.1	
2.0	††	Shear (soil) Tension (root)	166	196	211	216	201	SM	CL-ML	**	17.1	17.4	16.1	
2.0	0.20	Shear (soil) Tension (root)	172	194	199	227	243	SM	CL-ML	**	14.7	17.3	15.9	
1.7	0.16	**	179	221	221	187	191	SM	CL-ML	**	16.6	16.0	14.9	
2.0	0.14	Shear (soil) Tension (root)	154	162	164	159	181	SM	CL-ML	**	11.8	22.5	15.3	
2.1	0.21	Shear (soil) Tension (root)	179	248	275	283	294	SM	CL-ML	**	14.7	17.3	15.9	Entire crown was not overridden due to short departure lane
1.6	0.22	Shear (soil) Tension (root)	172	194	199	227	243	SM	CL-ML	**	14.7	17.3	15.9	
2.0	0.16	Shear (soil) Tension (root)	137	170	18[illegible]	174	173	SM	CL-ML	**	16.6	16.2	15.4	
1.7	0.06	Shear (soil) Tension (root)	199	179	160	174	162	SM	CL-ML	**	16.0	17.1	18.7	
1.7	0.16	Shear (soil) Tension (root)	130	193	178	159	187	SM	CL-ML	**	16.2	16.7	16.4	
1.8	0.19	Shear (soil) Tension (root)	176	167	134	146	183	SM	CL-ML	**	15.4	14.6	14.2	
2.0	0.19	Shear (soil) Tension (root)	144	136	155	203	175	SM	CL-ML	**	16.0	17.1	18.7	
1.9	0.27	Tension (root)	154	171	192	180	186	SM	CL-ML	**	15.6	18.3	17.9	
1.8	0.31	Shear (soil) Tension (root)	159	161	141	128	135	SM	CL-ML	**	11.8	22.5	15.3	
2.2	0.32	Shear (soil) Tension (root)	152	192	211	**	**	SM	CL-ML	**	**	**	**	
2.5	0.24	Shear (soil) Tension (root)	144	157	137	143	193	SM	CL-ML	**	16.4	16.4	17.9	
2.3	0.47	Shear (soil) Tension (root)	125	143	159	177	185	SM	CL-ML	**	15.6	18.3	17.9	
1.8	0.31	**	148	139	188	248	235	SM	CL-ML	**	17.1	17.4	16.1	
2.1	0.33	Shear (soil) Tension (root)	121	120	137	153	179	SM	CL-ML	**	16.0	17.1	18.7	
2.3	0.26	**	157	219	234	210	275	SM	CL-ML	**	16.6	16.0	14.9	
1.9	0.42	Shear (soil) Tension (root)	142	194	214	216	222	SM	CL-ML	**	17.1	17.4	16.1	
††	††	Shear (soil) Tension (root)	138	130	110	131	149	SM	CL-ML	**	15.6	18.3	17.9	
2.2	0.73	Shear (soil) Tension (root)	141	162	207	173	168	SM	CL-ML	**	17.1	17.4	16.1	Undercarriage of vehicle dragged on exposed root bulb
††	††	Compression (stem)	167	204	165	153	169	SM	CL-ML	**	16.8	16.4	16.2	Stem appeared to be infected at base
2.2	0.59	Shear (soil) Tension (root)	176	223	221	193	159	SM	CL-ML	**	16.4	15.9	16.4	Undercarriage of vehicle dragged on exposed root bulb
1.7	0.62	Shear (soil) Tension (root	145	166	201	232	227	SM	CL-ML	**	17.1	17.4	16.1	
3.4	0.99	Shear (soil) Tension (root)	175	198	214	243	219	SM	CL-ML	**	17.1	17.4	16.1	
1.5	0.72	Shear (soil) Tension (root)	175	241	211	199	209	SM	CL-ML	**	16.4	15.9	16.4	Front portion of tracks raised off the ground to complete override

B

Table B2

Summary of Data and Test Results, Bamboo Override Tests

Test No.	Test Site	No. of Stems	Average Single Stem Diameter in.	Clump Diameter in.	Work Required to Fail Clump, lb-ft	Contact Speed mph	Maximum Horizontal Pushbar Force lb	Maximum Longitudinal Acceleration g	Soils Data, Average Cone Index 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	18- to 24-in. Layer
227	4V-SBO	32	0.500	13.5	*	*	*	*	100	112	105	106
228	4V-SBO	40	0.375	19.0	1183	1.5	734	0.155	130	139	146	134
229	4V-SBO	35	0.500	21.5	3150	2.2	1405	0.207	113	144	151	148
230	4V-SBO	30	0.750	25.2	7102	2.0	1770	0.240	105	120	151	134
231	4V-SBO	54	0.500	34.4	6950**	2.7	2873	0.478	96	117	132	131
232	4V-SBO	47	0.550	30.6	5223	1.7	2288	0.193	110	115	120	132
233	4V-SBO	37	0.550	32.8	7800**	2.9	2988	0.191	106	124	145	219
234	4V-SBO	18	0.370	9.5	516	2.4	210	0.180	123	116	127	120
235	4V-SBO	17	0.370	7.6	645	1.8	278	0.162	129	131	148	132
236	4V-SBO	12	0.400	8.3	370	1.7	175	0.100	113	121	127	130
237	4V-SBO	16	0.550	10.5	728	1.8	326	0.100	143	136	148	150
238	4V-SBO	18	0.500	13.3	2060	1.8	1250	0.160	133	146	143	142
239	4V-SBO	45	0.690	21.3	3553**	1.9	2083	0.275	150	178	291	555
240	4V-SBO	40	0.875	30.6	*	2.0	3270	0.270	120	127	144	130
241	4V-SBO	54	0.500	28.0	5500**	1.9	2090	0.160	121	117	116	125
242	4V-SBO	12	0.500	11.8	825	2.0	401	0.128	143	153	157	148
243	4V-SBO	22	0.500	16.6	2460	2.1	1246	0.143	147	169	194	190
244	4V-SBO	32	0.500	21.0	2619	2.2	1191	0.200	125	149	153	146
245	4V-SBC	36	0.500	12.7	644	1.2	373	0.052	174	145	179	171
246	4V-SBO	10	0.410	8.0	105	1.1	57	0.000	133	136	143	130
247	4V-SBO	40	0.410	23.9	3927	1.5	1514	0.106	125	141	152	142
248	4V-SBO	14	0.410	19.4	2730	2.4	1233	0.080	114	137	138	125
249	4V-SBO	55	0.530	33.7	9880	7.7	4100	0.459	95	135	146	231
250	4V-SBO	48	0.560	27.6	6735	5.5	3723	0.601	127	14[illegible]	146	153

* Instrumentation failure.

** Bamboo clump failed but vehicle immobilized on top of clump.

Table B3

Summary of Data and Test Results, Multiple Tree Override Tests

Test No.	Test Site	Test Date	Push-bar Height in.	No. of Trees Over-ridden	Tree Type (Common Name)	Stem Diameter, in. 42 in. Aboveground Min	Max	Avg	Avg Tree Height ft	Mean Tree Spacing ft	Structural Cell Diam ft	Vehicle Speed mph	Length of Test Course ft	Distance Computed from Wheel or Track Revolution Count ft	Wheel or Track Slip %	Measured Values for Tests: Work Required to Fail Trees lb-ft	Measured Values for Tests: Avg Force Required to Fail Trees lb	Computed Values for Tests: Work Required to Fail Trees lb-ft	Computed Values for Tests: Avg Force Required to Fail Trees lb	Max Longitudinal Acceleration g	Avg Cone Index 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	USCS Soil Classification 0- to 6-in. Layer	6- to 12-in. Layer	Moisture Content % Dry Soil Weight 0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer
M37 3/4-ton Cargo Truck																												
455	E-12	5/11/65	26	11	Oak	2.1	3.5	2.9	20	5.4	24.1	1.5	37.0	*	*	19,647	531	13,801	373	*	80	108	108	SP-SM	SP-SM	4.0	3.1	*
458	E-15	5/11/65	26	8	Oak	1.3	4.4	2.6	18	5.8	25.9	1.5	26.0	*	*	5,772	222	4,290	165	*	72	84	93	SP-SM	SP-SM	2.3	2.5	*
459	E-16	5/11/65	26	8	Oak	2.7	4.1	3.2	20	4.5	20.1	1.5	21.0	*	*	21,231	1011	15,162	722	*	91	119	100	SP-SM	SP-SM	3.4	3.3	*
1	NASA-9	8/27/64	26	43	Pine	0.3	2.8	1.1	9	2.8	12.5	2.0**	37.5	41.5	9.6	6,786	181	5,094	136	*	234	237	*	CL	CL	*	*	*
2	NASA-5	8/27/64	26	36	Pine	0.9	3.8	1.8	14	3.1	13.8	2.0**	44.0	47.1	6.6	21,780	495	17,381	395	*	222	263	*	ML	ML	*	*	*
3	NASA-6	8/27/64	26	53	Pine	0.7	3.5	1.6	12	3.4	15.2	2.0**	77.0	77.8	1.0	26,103	339	20,144	262	*	475	688	675	ML	ML	10.6	10.3	10.5
4	NASA-7	8/27/64	26	10	Pine	1.1	4.6	3.1	20	4.4	19.6	2.0**	24.5	26.4	7.2	30,600	1249	21,486	877	*	318	356	241	CL-ML	CL-ML	*	*	*
M113 Armored Personnel Carrier (APC)																												
7	NASA-3	11/16/64	26	34	Pine	3.0	6.0	4.3	36	6.3	28.3	4.0	122.0	125.6	2.9	290,480	2381	165,815	1359	0.55	330	466	513	CL-ML	CL-ML	*	*	*
9	NASA-11	11/16/64	26	17	Pine	1.8	6.7	4.6	41	6.6	29.3	3.6	62.0	75.4	17.8	226,720	3657	115,272	1859	0.75	[illegible]	470	504	ML	ML	10.8	13.8	15.9
10	NASA-12	11/16/64	26	11	Pine	3.6	8.8	6.1	47	7.8	34.9	2.5	52.0	60.0	20.0	231,920	4460	133,380	2565	0.90	134	168	246	ML	ML	22.2	15.4	14.8
11	NASA-10	11/16/64	26	18	Pine	1.5	8.8	4.5	39	6.8	30.4	2.6	74.5	79.0	7.0	234,160	3143	136,931	1838	0.95	371	683	713	ML	ML	17.0	14.2	15.1
12	NASA-10	11/16/64	26	7	Pine	3.5	6.9	4.5	41	6.3	28.3	4.1	25.0	35.0	28.6	74,600	2992	45,414	1817	0.70	442	687	669	ML	ML	*	*	*
13	NASA-8A	11/16/64	26	27	Pine	1.7	5.6	3.5	32	4.8	21.5	3.6	55.5	60.0	7.5	147,000	2649	88,552	1596	0.92	287	[illegible]	504	*	*	17.6	17.9	18.8
3A	NASA-3	11/16/64	38	43	Pine	2.5	6.0	4.4	37	7.4	32.9	9.4	232.0	*	*	411,000	1765	249,830	1077	0.80	186	330	466	CL-ML	CL-ML	*	*	*
4A	NASA-3	11/16/64	38	51	Pine	2.5	6.5	4.3	38	7.0	31.3	10.1	294.0	*	*	144,000	1500	271,335	923	1.40	186	330	466	CL-ML	CL-ML	*	*	*

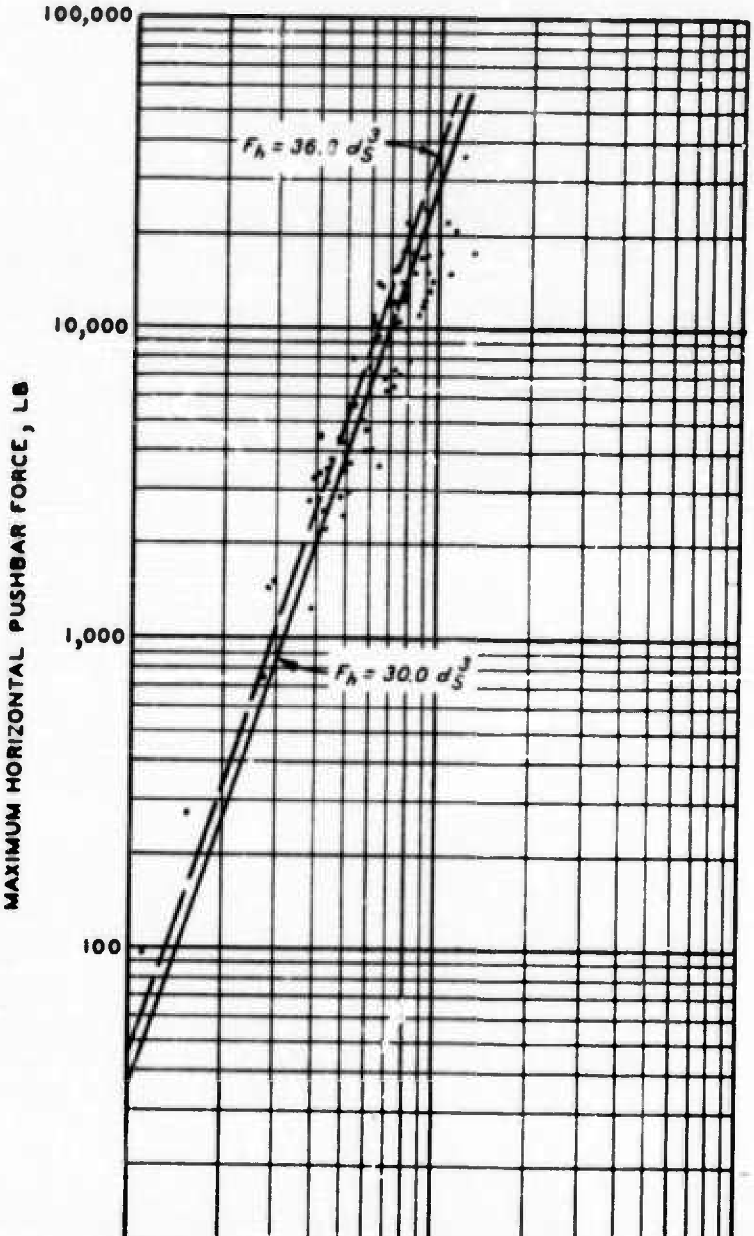
* No measurement made.
** Approximate.

Table B4

Summary of Distances Required to Fail Trees

Test No.	Tree (Common Name)	Stem Diameter in.	Distance ft
	20-in. Pushbar Height		
34	Hieng	13.0	6.70
35	Hieng	5.0	3.90
36	Hieng	7.2	4.30
37	Hieng	6.7	7.75
38	Hieng	7.4	4.10
39	Hieng	5.8	5.50
40	Hieng	4.8	2.10
41	Hieng	8.0	4.30
42	Hieng	6.4	4.70
46	Hieng	6.1	2.20
47	Hieng	5.0	3.30
48	Hieng	7.5	8.10
49	Hieng	8.8	4.10
50	Hieng	10.0	5.50
51	Hieng	10.7	6.50
52	Hieng	9.1	4.80
54	Hieng	5.1	6.70
55	Hieng	4.8	3.50
56	Hieng	4.3	3.20
57	Hieng	5.8	2.80
58	Hieng	6.0	5.40
59	Hieng	3.9	2.60
61	Hieng	4.9	3.30
62	Hieng	2.7	6.80
16	Pine	6.1	6.00
17	Pine	5.1	5.30
18	Pine	5.5	5.40
19	Pine	7.9	5.60
20	Pine	6.4	5.50
21	Pine	4.3	8.00
22	Pine	5.1	6.40
23	Pine	7.1	7.70
24	Pine	8.3	8.60
25	Pine	4.3	7.10
26	Pine	4.9	4.30
27	Pine	8.0	7.00
28	Pine	7.0	6.00
29	Pine	7.9	6.40
30	Pine	7.3	5.50
31	Pine	7.6	6.80
32	Pine	6.4	5.20
34	Pine	[illegible]	9.40
35	Pine	[illegible]	6.00
38	Pine	6.6	9.00
40	Pine	3.6	9.20
147	Pine	7.1	6.00
149	Pine	7.9	5.70
153	Pine	8.3	6.40
154	Pine	9.0	7.40
		Average distance	5.67

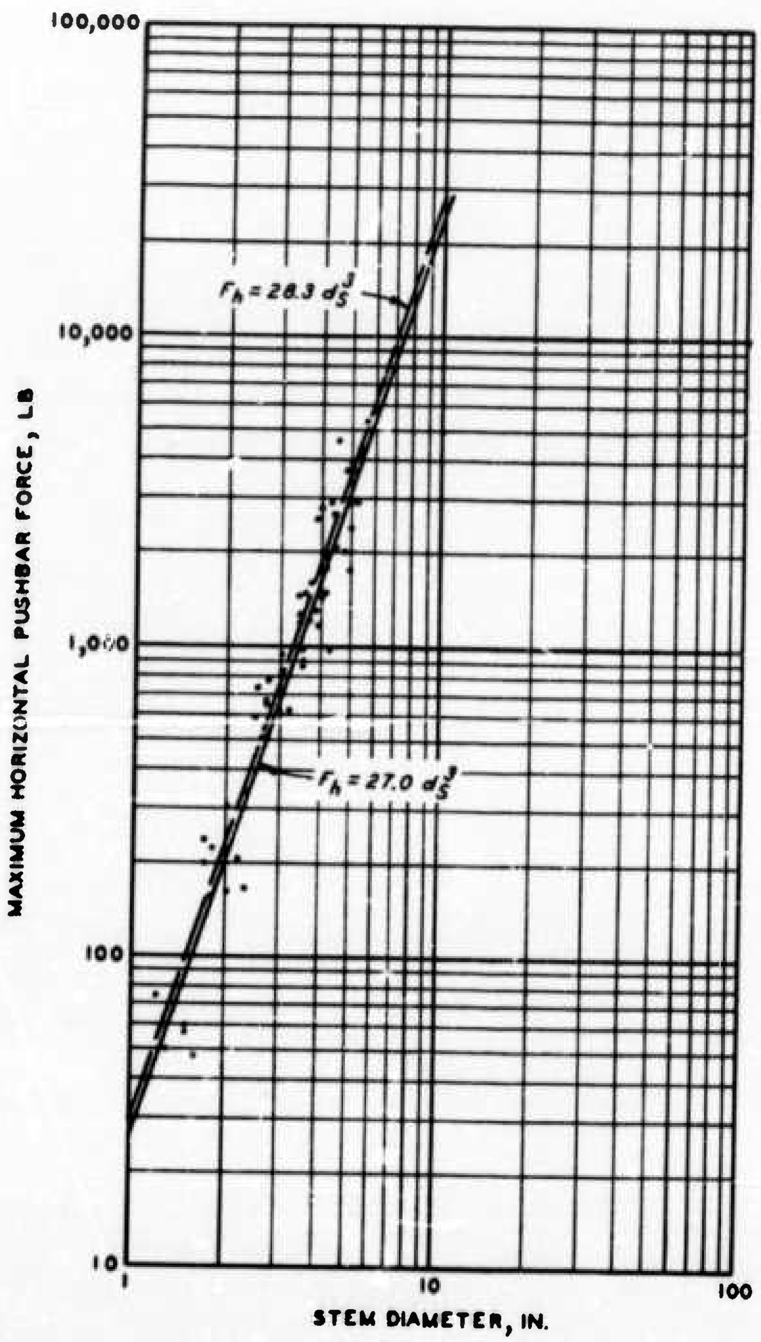
Test No.	Tree (Common Name)	Stem Diameter in.	Distance ft
	26-in. Pushbar Height		
1	Pine	1.8	3.70
5	Pine	4.1	4.20
6	Pine	2.7	6.10
7	Pine	4.0	4.00
8	Pine	4.5	5.40
9	Pine	3.5	3.50
11	Pine	4.5	5.20
12	Pine	4.1	5.40
13	Pine	3.9	5.50
14	Pine	4.8	6.20
16	Pine	3.5	5.80
17	Pine	3.6	5.80
19	Pine	2.3	4.80
20	Pine	2.7	7.10
21	Pine	5.0	6.90
22	Pine	3.2	8.20
23	Pine	5.3	4.90
26	Pine	2.2	6.50
27	Pine	3.4	5.40
30	Oak	1.5	6.90
31	Oak	1.7	6.60
34	Oak	2.3	5.40
38	Oak	3.7	6.60
39	Oak	5.2	5.30
40	Oak	5.0	7.30
41	Oak	3.9	6.10
42	Oak	2.5	4.10
43	Oak	5.3	7.70
44	Oak	4.0	5.10
		Average distance	5.71
	32-in. Pushbar Height		
1	Hieng	2.0	4.40
2	Hieng	2.3	4.25
3	Hieng	2.9	6.15
4	Hieng	7.3	5.75
5	Hieng	4.0	4.60
6	Hieng	3.1	7.60
7	Hieng	2.2	5.15
8	Hieng	2.0	6.00
9	Hieng	4.7	6.50
11	Hieng	4.6	8.20
12	Hieng	6.4	7.50
13	Hieng	5.6	7.10
14	Hieng	8.4	7.70
15	Hieng	6.4	5.30
16	Hieng	4.0	8.50
17	Hieng	6.1	3.00
18	Hieng	7.4	8.50
19	Hieng	4.8	4.00
20	Hieng	4.9	8.70
21	Hieng	5.0	7.00
26	Hieng	2.9	4.00
27	Hieng	4.0	3.80
28	Hieng	5.1	5.00
29	Hieng	3.3	5.00
30	Hieng	2.7	7.60
31	Hieng	3.9	3.20
32	Hieng	4.0	7.00
33	Hieng	9.7	4.50
		Average distance	5.93



SINGLE STANDING TREE OVERRIDE TESTS

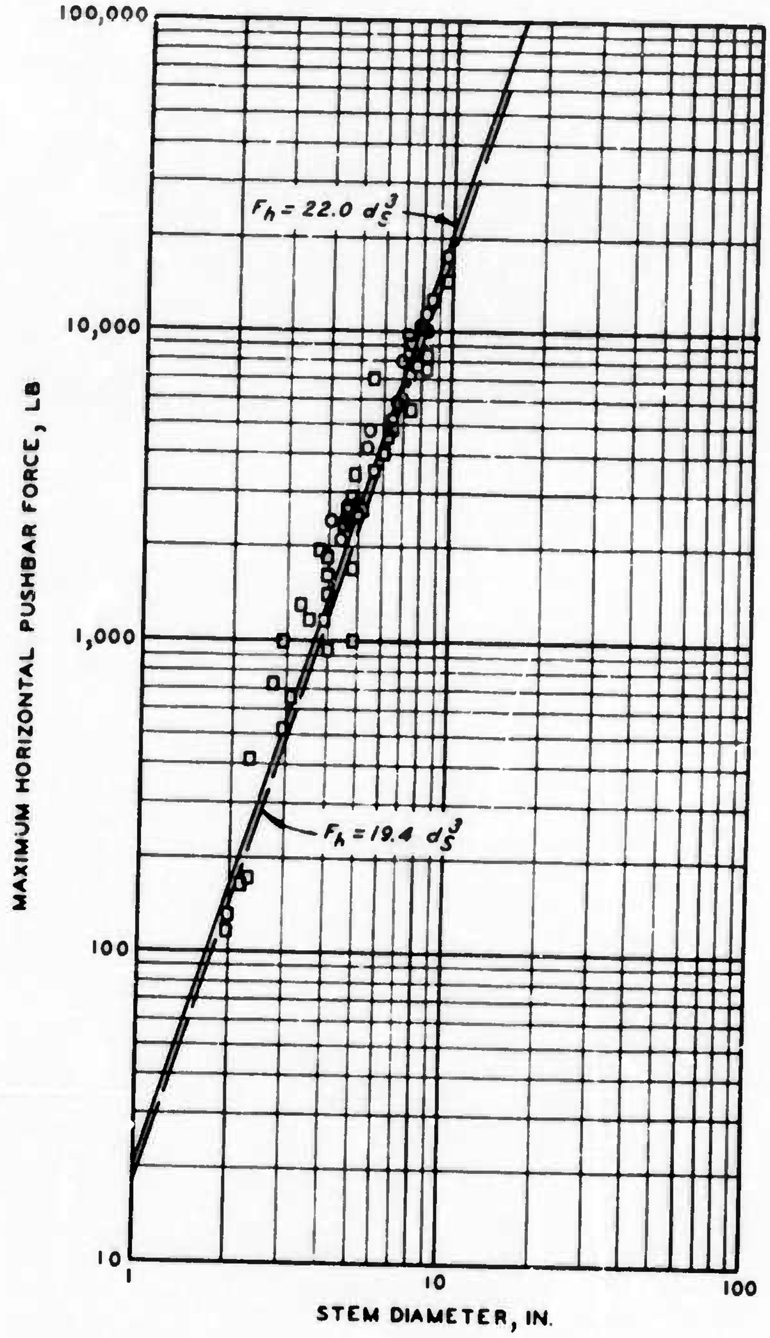
FORCE REQUIRED TO FAIL TREE

PUSHBAR HEIGHT 20 IN.
SPEED RANGE 0-3.9 MPH



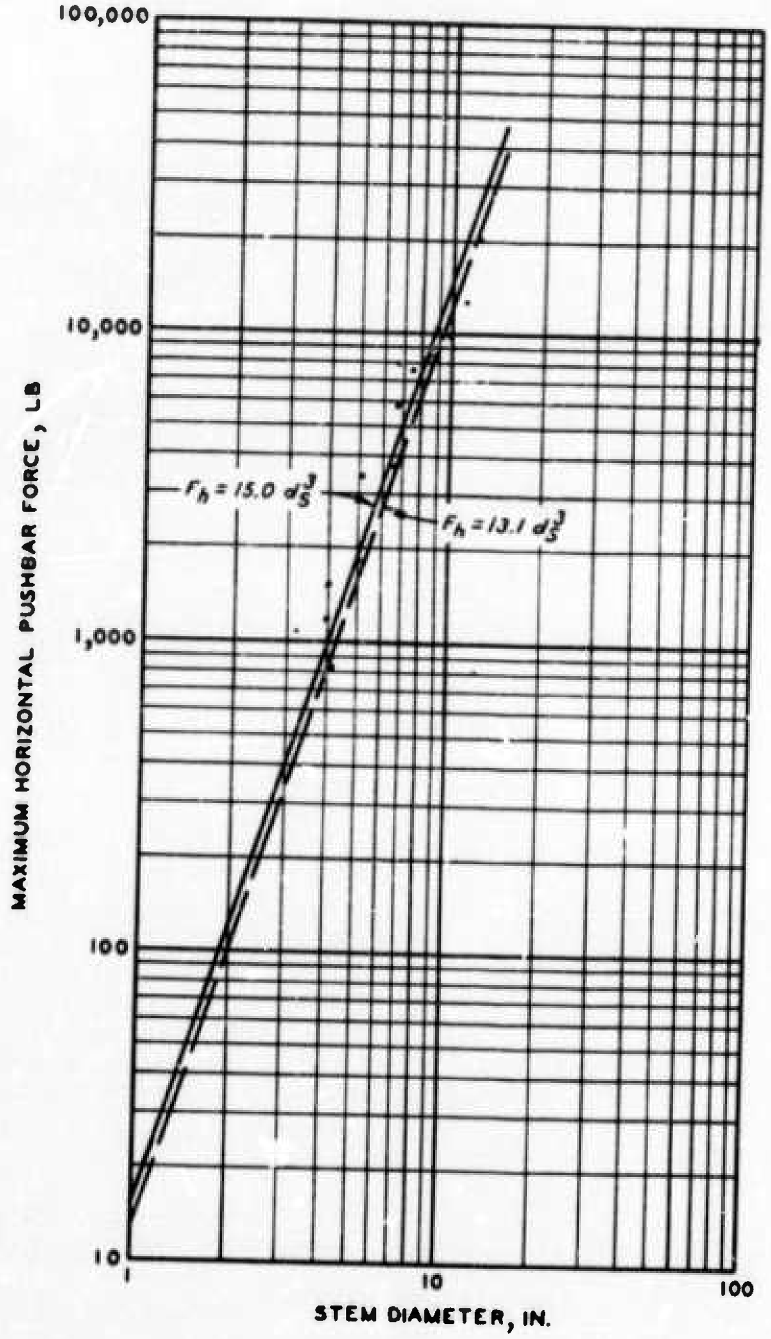
SINGLE STANDING TREE
OVERRIDE TESTS
FORCE REQUIRED TO FAIL TREE
PUSHBAR HEIGHT 28 IN.
SPEED RANGE 0-3.9 MPH

PLATE B2



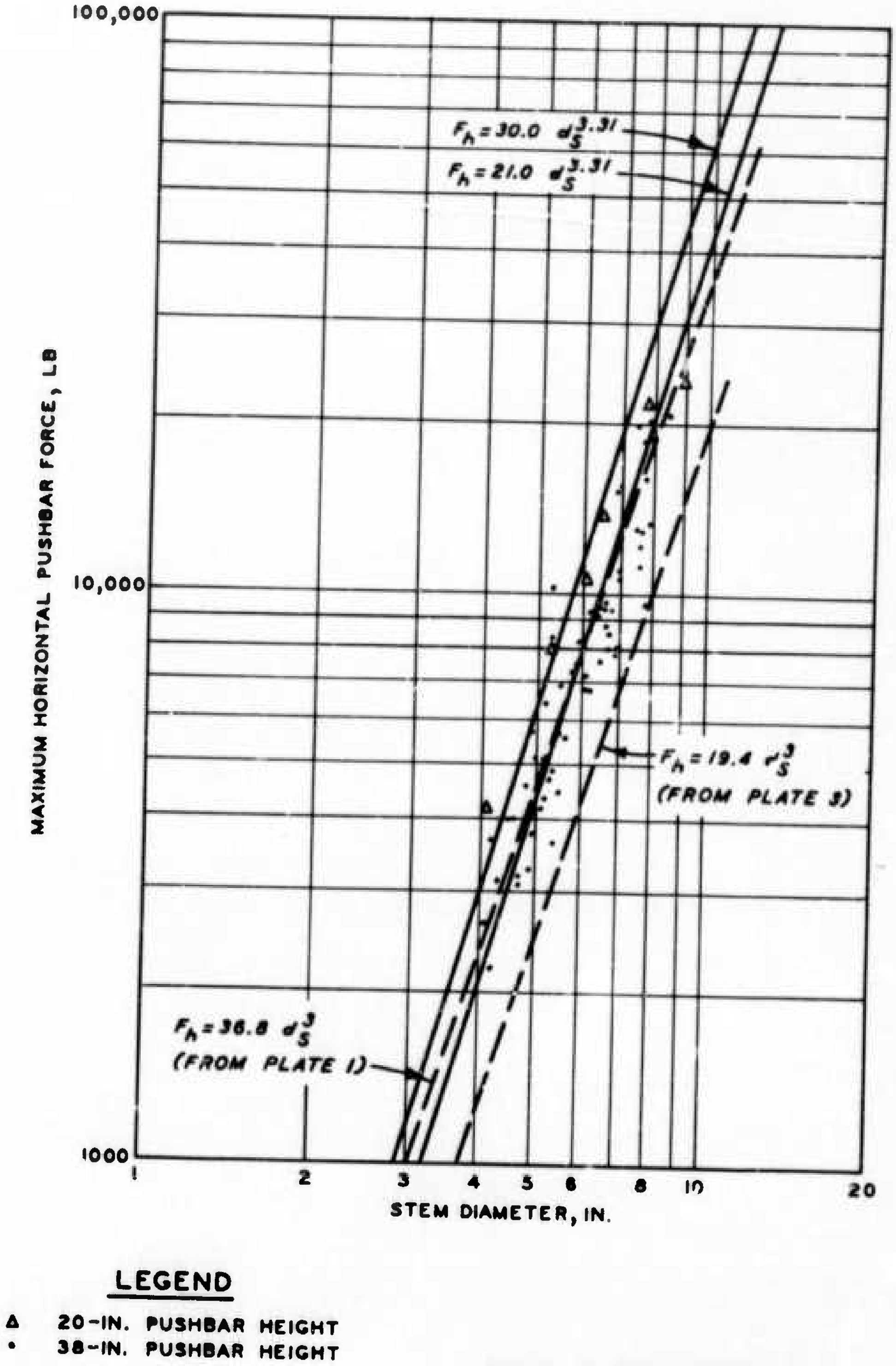
LEGEND
□ 32-IN. PUSHBAR HEIGHT
○ 38-IN. PUSHBAR HEIGHT

SINGLE STANDING TREE
OVERRIDE TESTS
FORCE REQUIRED TO FAIL TREE
PUSHBAR HEIGHT 32 AND 38 IN.
SPEED RANGE 0-3.9 MPH

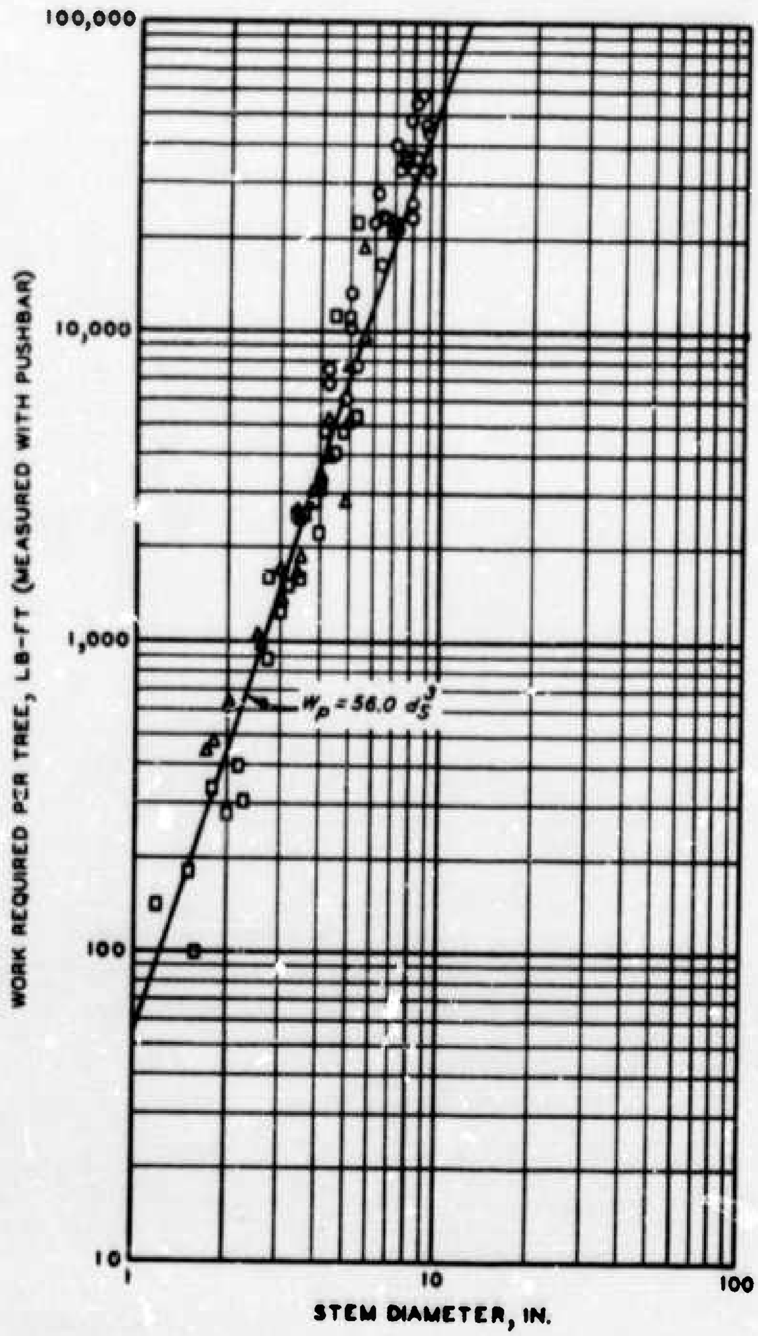


SINGLE STANDING TREE
OVERRIDE TESTS
FORCE REQUIRED TO FAIL TREE
PUSHBAR HEIGHT 56 IN.
SPEED RANGE 0-3.9 MPH

PLATE B4



SINGLE STANDING TREE
OVERRIDE TESTS
FORCE REQUIRED TO FAIL TREE
SPEED RANGE 4-17 MPH



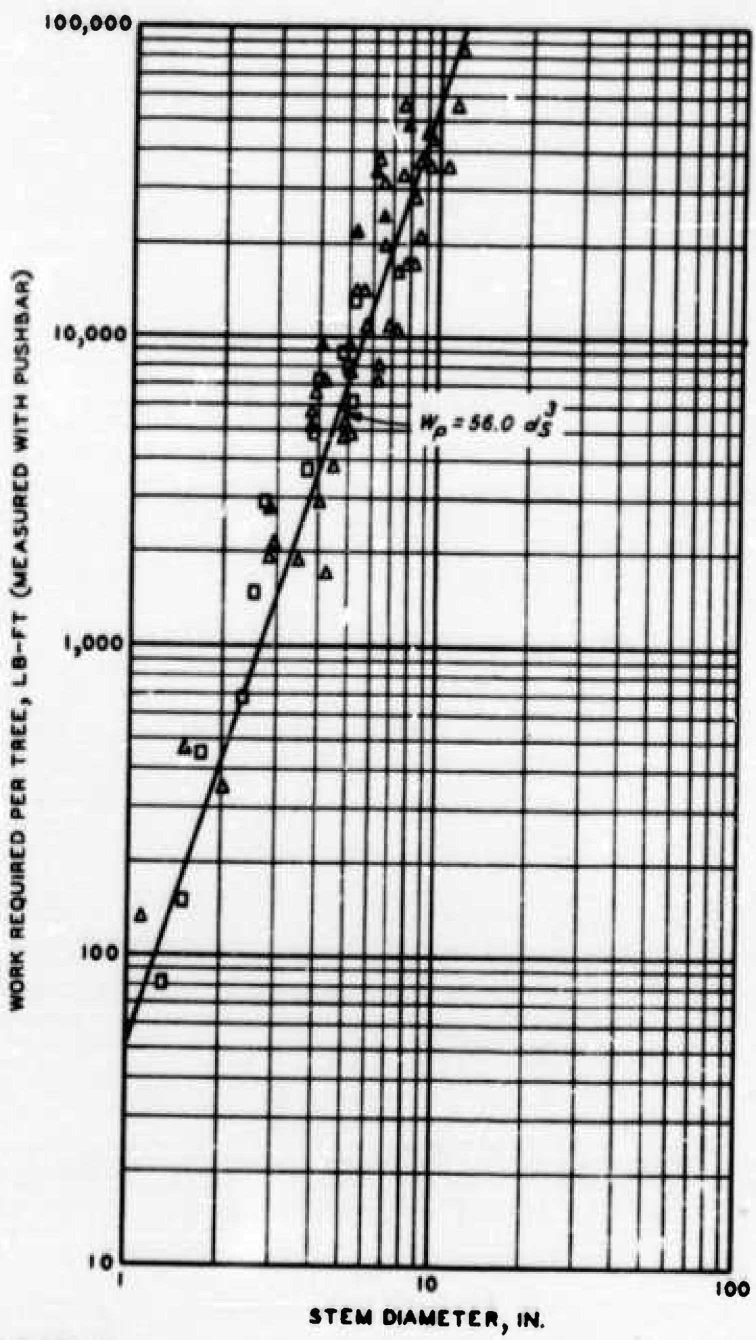
LEGEND

- □ NASA MARSHALL SPACE FLIGHT CENTER, MISS., AUG 1964
- ○ NASA MARSHALL SPACE FLIGHT CENTER, MISS., NOV 1964
- △ EGLIN AFB. FLA., MAY 1965

SINGLE STANDING TREE OVERRIDE TESTS

WORK REQUIRED TO FAIL TREE CONIFERS IN THE UNITED STATES

PLATE B6



LEGEND

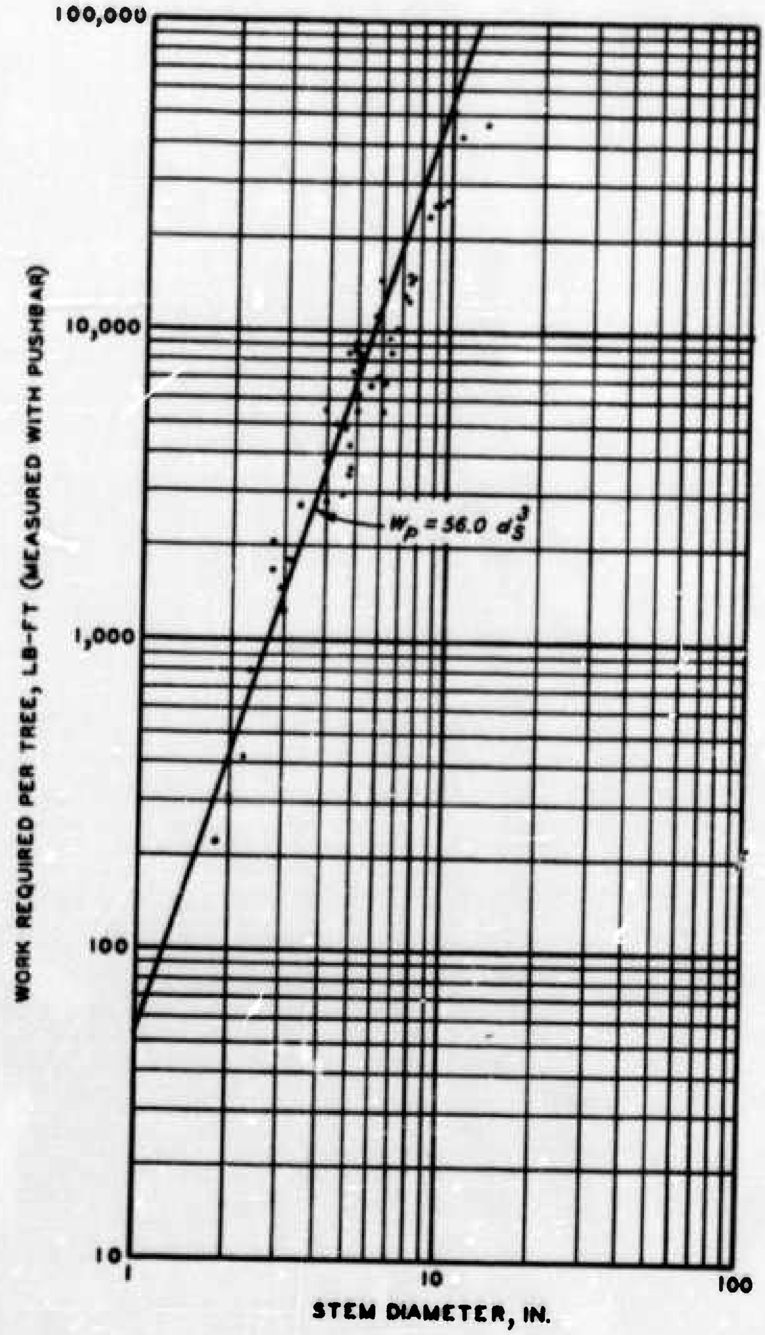
△ EGLIN AFB, FLA., MAY 1965, SPEED RANGE 0 - 3.9 MPH

▲ EGLIN AFB, FLA., MAY 1965, SPEED RANGE 4 - 12 MPH

□ NASA MARSHALL SPACE FLIGHT CENTER, MISS., AUG 1964, SPEED RANGE 0 - 3.9 MPH

SINGLE STANDING TREE OVERRIDE TESTS

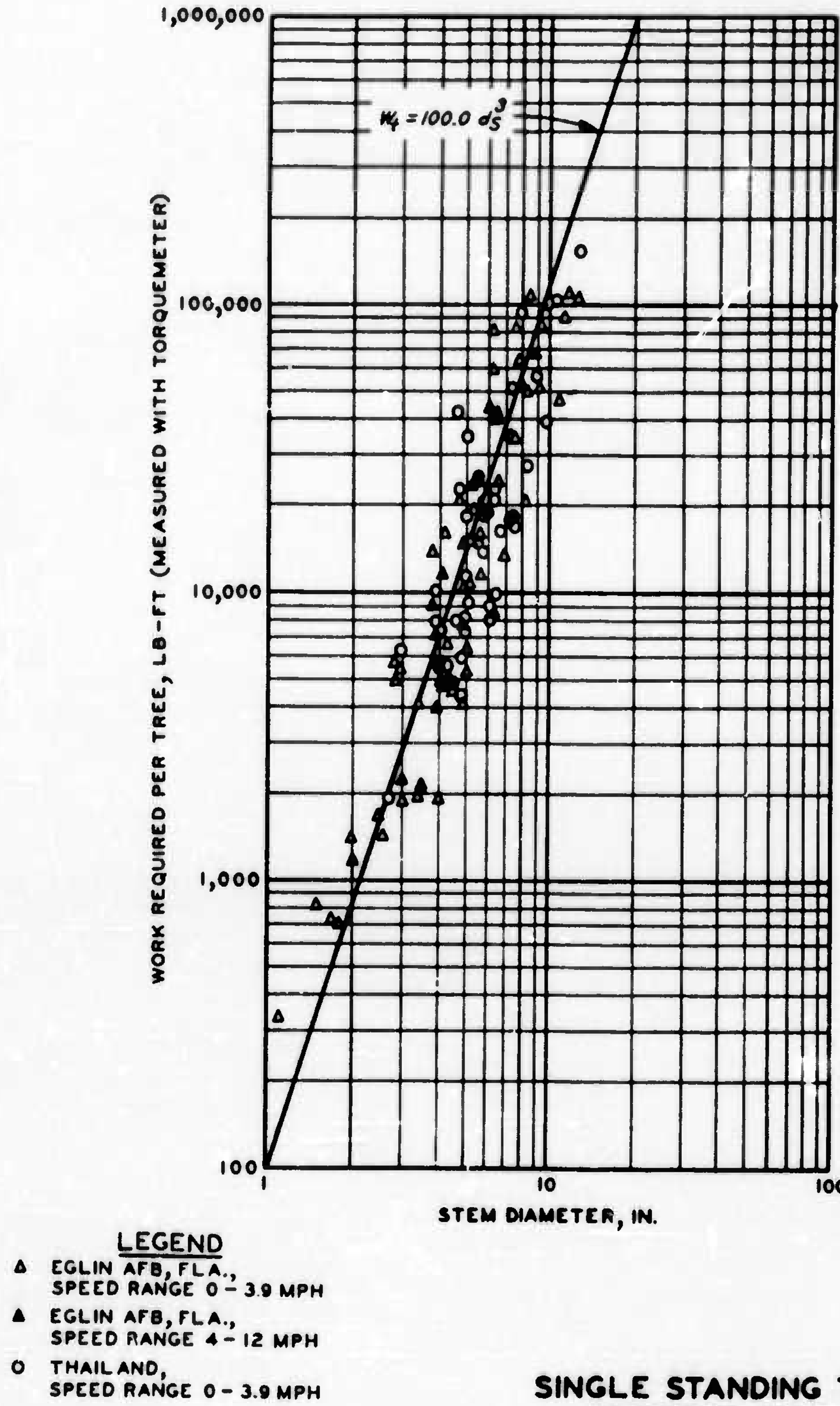
WORK REQUIRED TO FAIL TREE
HARDWOODS IN THE UNITED STATES



SINGLE STANDING TREE OVERRIDE TESTS

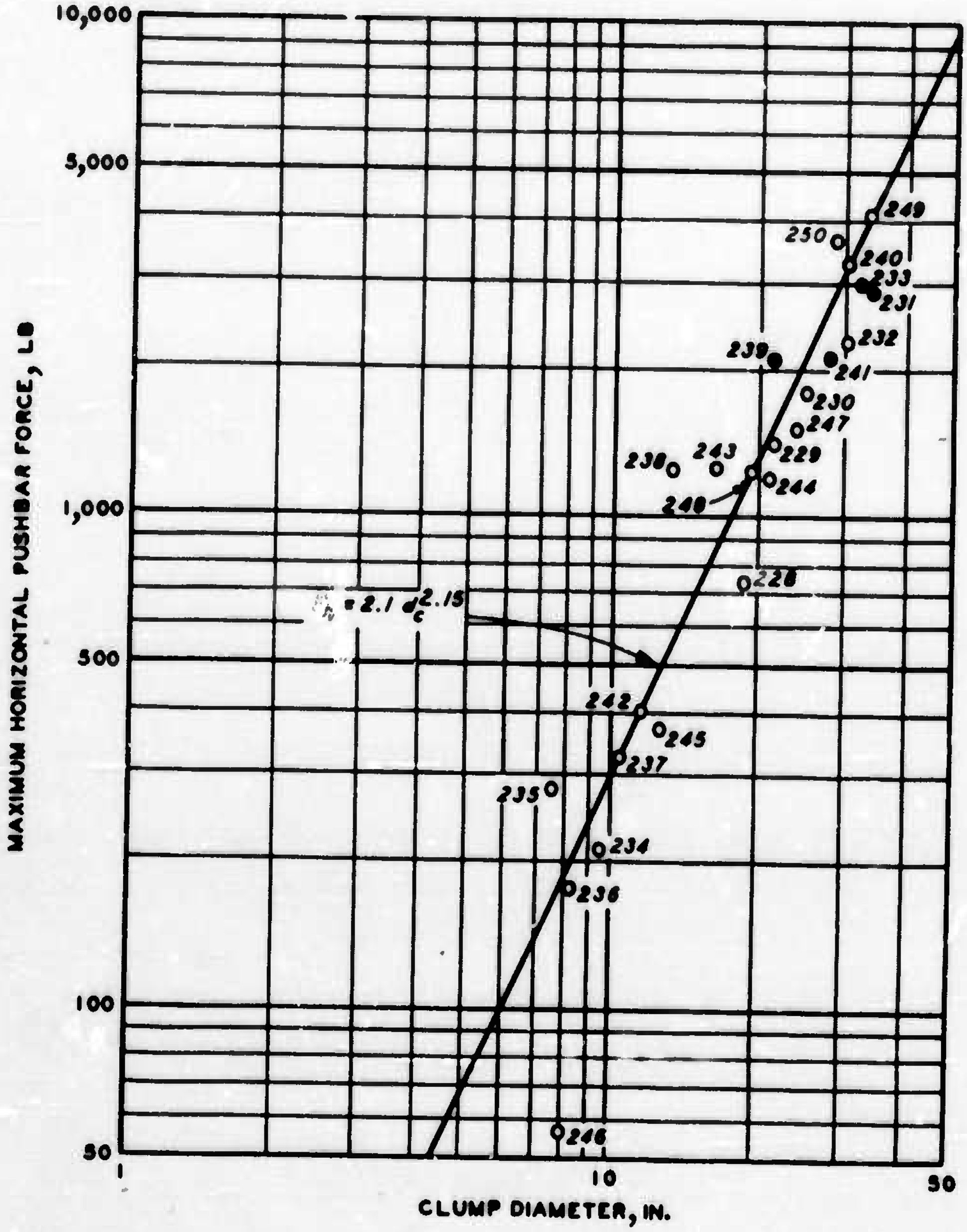
WORK REQUIRED TO FAIL TREE HARDWOODS IN THAILAND

PLATE B8



SINGLE STANDING TREE OVERRIDE TESTS

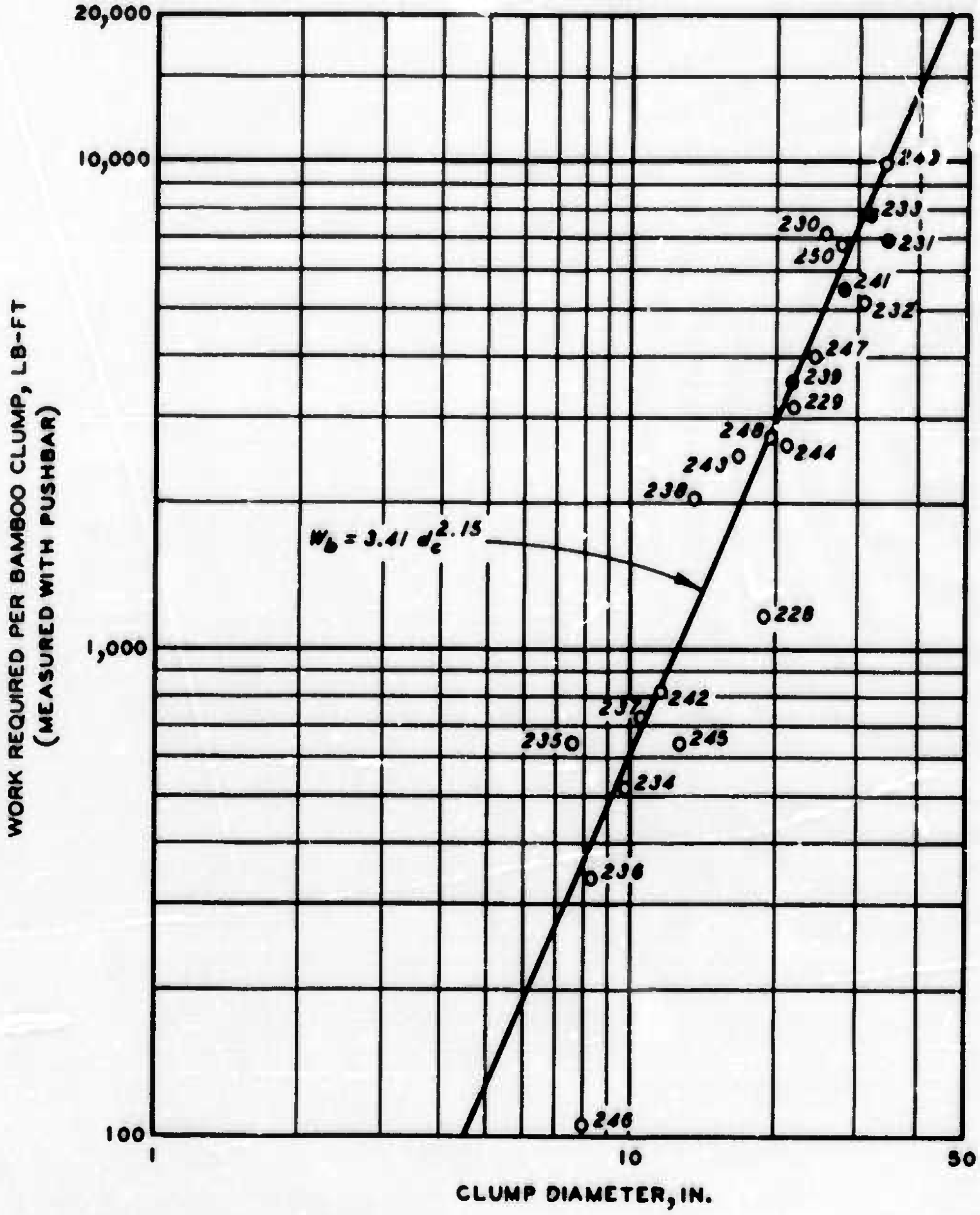
WORK REQUIRED TO OVERRIDE TREE



NOTE: NUMBERS NEAR PLOTTED POINTS INDICATE TEST NUMBER IN TABLE 2.

● DENOTES BAMBOO CLUMP FAILED BUT VEHICLE IMMOBILIZED ON TOP OF CLUMP.

BAMBOO OVERRIDE TESTS
FORCE REQUIRED
TO FAIL BAMBOO CLUMP

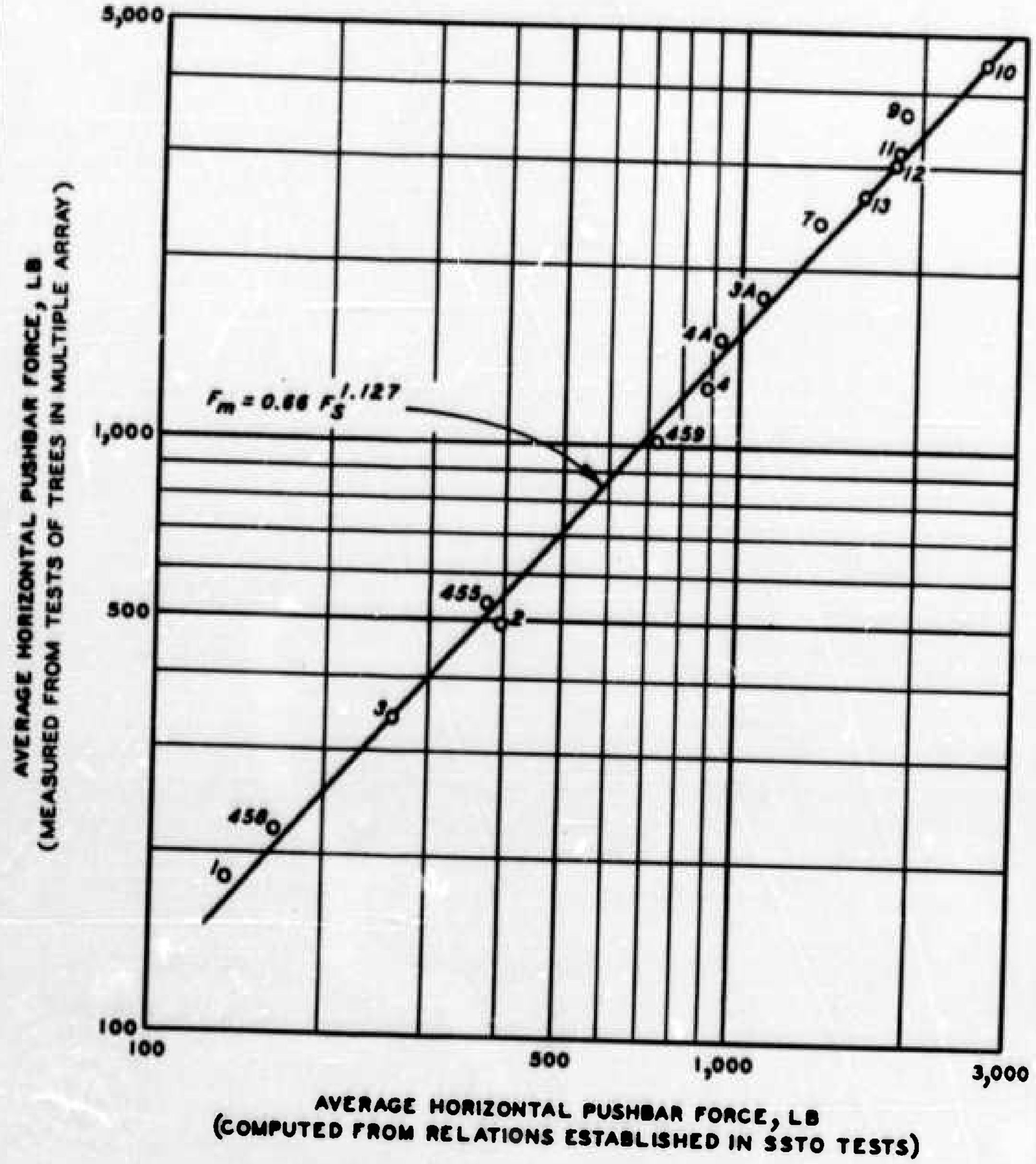


NOTE: NUMBERS NEAR PLOTTED POINTS INDICATE TEST NUMBER IN TABLE 2.

● DENOTES BAMBOO CLUMP FAILED BUT VEHICLE IMMOBILIZED ON TOP OF CLUMP.

BAMBOO OVERRIDE TESTS

WORK REQUIRED TO FAIL BAMBOO CLUMP

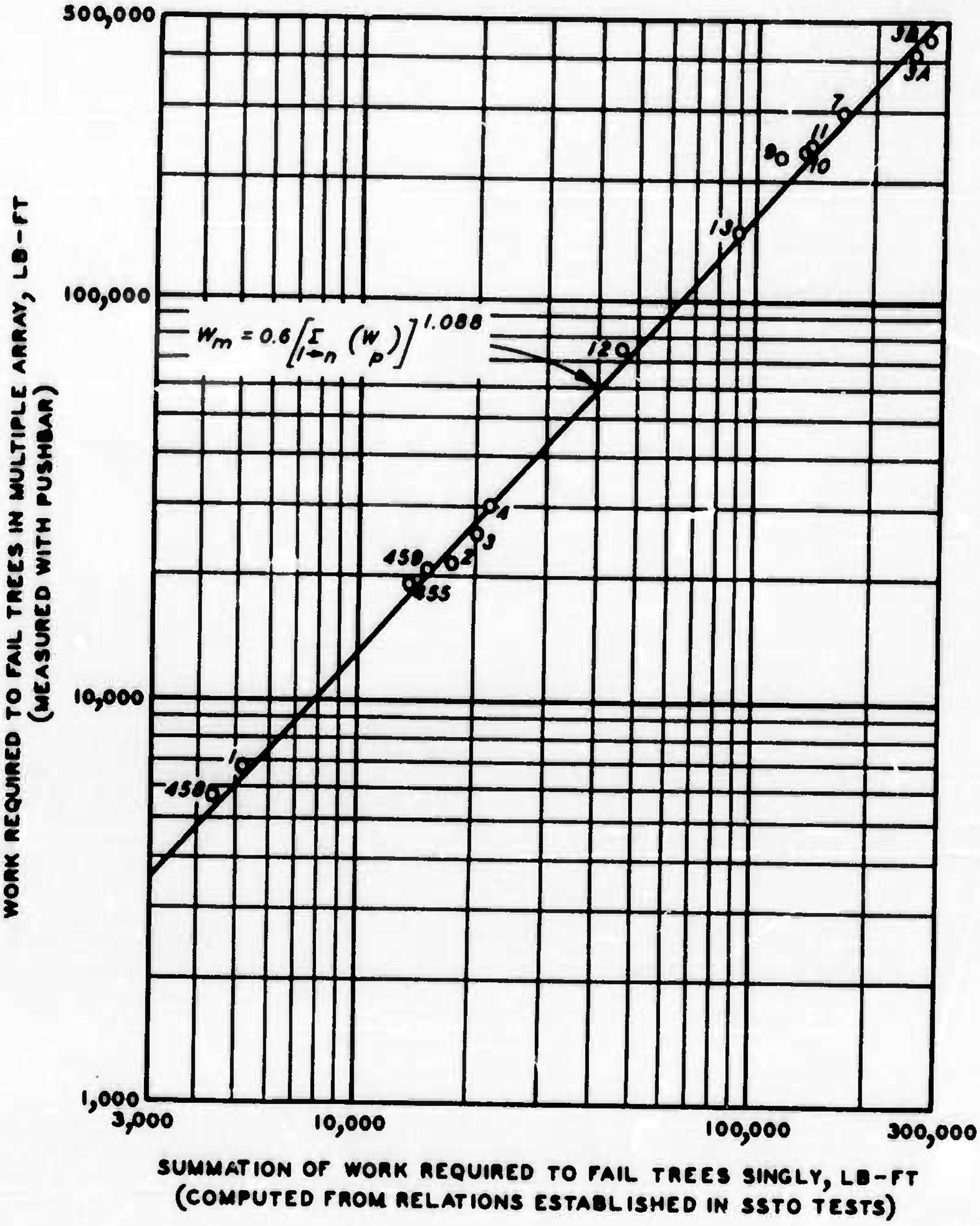


NOTE: NUMBERS NEAR PLOTTED POINTS INDICATE TEST NUMBER IN TABLE 3.

SSTO INDICATES SINGLE STANDING TREE OVERRIDE.

MULTIPLE TREE OVERRIDE TESTS
COMPARISON OF AVERAGE FORCE REQUIRED TO FAIL TREES SINGLY AND IN MULTIPLE ARRAY

PLATE B12



NOTE: NUMBERS NEAR PLOTTED POINTS INDICATE TEST NUMBER IN TABLE 3.

SSTO INDICATES SINGLE STANDING TREE OVERRIDE.

MULTIPLE TREE OVERRIDE TESTS

COMPARISON OF WORK REQUIRED TO FAIL TREES SINGLY AND IN MULTIPLE ARRAY

BLANK PAGE

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Engineer Waterways Experiment Station Vicksburg, Mississippi	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
AN ANALYTICAL MODEL FOR PREDICTING CROSS-COUNTRY VEHICLE PERFORMANCE; APPENDIX B: VEHICLE PERFORMANCE IN LATERAL AND LONGITUDINAL OBSTACLES VOLUME II: LONGITUDINAL OBSTACLES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Appendix B, Volume II, to final report

5. AUTHOR(S) (First name, middle initial, last name)
Claude A. Blackmon
Donald D. Randolph

6. REPORT DATE July 1968	7a. TOTAL NO. OF PAGES 66	7b. NO. OF REFS 4
8a. CONTRACT OR GRANT NO. ARPA Order No. 400 b. PROJECT NO. 1-V-0-25001-A-131 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report No. 3-783 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. DISTRIBUTION STATEMENT
This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of U. S. Army Engineer Waterways Experiment Station.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency and Development Directorate, U. S. Army Materiel Command

13. ABSTRACT
A total of 372 tests were conducted with one tracked and one wheeled vehicle at the NASA Marshall Space Flight Center, Miss., Eglin Air Force Base, Fla., Pran Buri, Thailand, and Khon Kaen, Thailand. The general purpose of these tests was to obtain data relating characteristics of longitudinal obstacles to vehicle performance in terms suitable for use in developing that portion of the analytical model for cross-country performance. () The specific purposes were (a) to determine the maximum horizontal force and total work required to override single standing trees of a range of sizes at various speeds and pushbar heights and (b) to determine average horizontal force and total work required to override trees in multiple array. Empirical relations are presented to support the conclusions that pushbar force required to fail trees singly and in multiple array, work required to fail trees singly and in multiple array, and work required to override a single standing tree may be predicted from stem diameter(s). A method is suggested for predicting work required to override trees in multiple array. The results of the tree-felling tests in the Tunguska meteorite area were confirmed, with a single exception noted, and discussed. It is recommended that additional testing be done in areas of soft soil to determine the effect of soil strength on uprooting, and in grass and brush areas to determine the effect of small vegetation on speed.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Mathematical models						
Obstacles						
Cross-country terrain						
Terrain -- Thailand						
Vehicles, military						
Vehicles -- testing						